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WILLIAM HARKNESS.*

PROFESSOR FRANK H. BIGELOW.

FOR POPULAR ASTRONOMY.

William Harkness, Professor of Mathematics, U. S. N., the son of Rev. Dr. James and Jane (Weild) Harkness, was born at Ecclefechan, Scotland, on December 17, 1837, and died in Jersey City, N. J., on February 23, 1903. He was one of the founders of this Society, its President in 1887, a constant attendant upon its sessions, contributing papers of value to its proceedings and participating in its discussions. He was never married, and for many years made his residence in the rooms of the Cosmos Club, of which he was also a founder, where his genial society and delightful conversation was freely enjoyed by the scientific circle of Washington. He made many warm friends in his walk through life, and their personal sorrow is mingled with a wide spread regret that he was not able to finish several incomplete pieces of work, which had been postponed in consequence of the burden of duties devolving upon him as Astronomical Director of the U. S. Naval Observatory and Director of the Nautical Almanac offices during the last years of his official career. His colleagues expressed their own feelings regarding him in these words: "Throughout all his connection with the Observatory, for 37 years previous to his retirement in 1899, a conscientious faithfulness even to the minutest details characterized the performance of all his duties. This adherence to duty was so rigidly carried out by him that he rarely gave himself the occasional relaxation so necessary to the recuperation of wearied energies, which might have added years of usefulness to his life. During the past year it has been a special cause of regret to him that feebleness of body should compel him to forego participation in scientific work; meanwhile continually hoping soon to recover strength sufficiently to permit his return to Washington to complete various pieces of scientific work. His energy and faithfulness should be emulated by all. His example should spur us on to

* Read before the Philosophical Society of Washington, May 23, 1903.

greater faithfulness, activity and zeal in carrying on labors commenced by him and providentially committed to us to continue."

William Harkness was a man of the highest moral principles, hating sham in science, in society, and in the state, and freely expressing his appreciation of truth as he saw it. He was endowed with a mind of unusual penetration which went to the heart of scientific and social problems with unerring precision, and his memory of details and facts made his suggestions as to their connection with general principles valuable and instructive. His own tastes led him to pursue astronomy rather more on the practical side than on the theoretical, and he was concerned with devising and constructing instruments of precision more than in developing the analytical formulæ of the subject. He was a mathematician of ability as his numerous memoirs demonstrate, but he was especially pleased to discover the formula which contained exactly the mechanical dimensions and the physical process in compact form.

His work on the Solar Parallax and Its Related Constants, in which are correlated the numerous determinations of the constants of the solar system, and his theory of the focal curve of achromatic telescopes, and probably best known to science in general. At the Observatory there is hardly a piece of apparatus in use at the present time which is not either the work of his mind, or which does not embody essential features which he suggested. He drew up the specifications for constructing the 12-inch equatorial telescope, and for remounting the 26-inch equatorial, the 8.5-inch transit circle, the meridian transit, and the prime vertical transit in 1891; for constructing the new 6-inch steel transit circle in 1894; and the 5-inch steel alt-azimuth in 1895. In these instruments dials were introduced, and placed conveniently near the observer, to indicate the position of the telescope; the flexure of the 6-inch transit circle and the 5-inch alt-azimuth instrument was reduced to a minimum by using for the tubes and axes single pieces of steel machined on the inside and the outside. In 1875 he devised instruments for measuring accurately the relative positions of Venus and the Sun as shown on the photographs taken during the transit of Venus, Decemher 9, 1874. He invented the spherometer caliper in 1877, which is the most accurate instrument known for determining the figure of the pivots of astronomical instruments. He made extensive experiments in photography with the view of determining the best reagents, and form of apparatus, for photographing the solar corona.

He took part in numerous expeditions for scientific and astro-

nomical observations. In 1865-1866 on the U. S. Monitor *Monadnock* he studied the effect of the iron armor in modifying the magnetic indications of the compass, and determined the magnetic elements at many ports in a cruise from Philadelphia around South America to San Francisco. The Smithsonian Institution published the report on this magnetic work in 1871, in a quarto volume of 225 pages. He observed the total eclipse of the Sun, August 7, 1869, at Des Moines, Iowa, and there discovered the coronal line K 1474; the total solar eclipse of December 22, 1870, at Syracuse, Sicily; the transit of Venus at Hobart, Tasmania, on December 9, 1874; the transit of Mercury at Austin, Texas, May 6, 1878, the total solar eclipse at Creston, Wyoming, July 29, 1873; the transit of Venus at Washington, D. C., December 6, 1882. He was appointed member of the U. S. Transit of Venus Commission in 1871, served on this commission in devising apparatus and fitting out the United States Expeditions for the transits of 1874 and 1882; was assigned to duty in 1875 for reducing the observations made by these parties, measured the photographic plates with new apparatus, published a paper in 1882, on the "Relative Accuracy of Different Methods of Determining the Solar Parallax," defending the continued use of photography; and finally, in February, 1889, published the resulting parallax, as derived from the discussion of these observations. In 1881-1883 he was at work upon the reduction of the zones of stars, observed by J. H. Gilliss, Santiago, Chili, during the years 1849-1852; after some interruption, for lack of funds, it was completed and published in 1895. In May 1876 he set up the government exhibit at the Centennial Exposition at Philadelphia, Pa. His publications cover reports on all these numerous works, besides many scientific papers in various journals. In his travels he visited nearly all countries of the world, and acquired a very extensive knowledge of men and affairs, which moulded his conversation and judgment in maturer years, as mentioned above.

He entered Lafayette College, Easton, Pa., in 1854, but removed with his parents to Rochester, N. Y., and graduated with an A. B. at the Rochester University in 1858, receiving the degrees of A. M. in 1861, and LL. D. in 1874, from his Alma Mater. Studied medicine in New York, and received the degree of M. D. in 1862. Was a reporter on newspapers in 1858 and 1860; was appointed aid in astronomy at the U. S. Naval Observatory, August 1, 1862; served as surgeon at the second battle of Bull Run, August 30, 1862; commissioned Professor of Mathematics

U. S. N., August 24, 1863; served with the army during Early's attack on Washington, July 11-12, 1864; served on the U. S. Monitor Monadnock, October 17, 1865 to June 23, 1866 and was present at the bombardment, by the Spanish fleet, of Valparaiso March 31, 1866, and of Callas, May 2, 1866; was attached to the Hydrographic office, October 14, 1866 to October 1, 1867; was transferred to the U. S. Naval Observatory, October 1, 1867 and remained till his retirement December 17, 1899. He was made lieutenant-commander, August 24, 1863; commander, May 31, 1872; captain, April 17, 1878, and rear-admiral December 17, 1899. He was appointed chief astronomical assistant to the Superintendent of the Naval Observatory September 21, 1894, and Director of the Nautical Almanac, June 30, 1897. He was vice president of the American Association for the Advancement of Science in 1881, 1885, and its president in 1893; he was a member of several scientific societies in the United States and Europe.

It is evident from this long and honorable record that the Philosophical Society has reason to be proud of this distinguished career of one of its most devoted members.

ON THE MOTIONS OF THE PLANETS.*

F. R. MOULTON.

For Popular Astronomy.

It very frequently happens that readers of astronomy who have not entered into the mathematical discussions of the subjects involved, get somewhat confused and erroneous ideas concerning the motions of the planets. The various propositions respecting the motion of two mutually attracting spheres, the solutions of the problem of three bodies, the stability of the solar system and related problems depend upon somewhat advanced mathematical processes. The difficulties of the methods and their length are such that they cannot be presented here; it will be necessary for us to content ourselves with a statement of facts and with illustrations for making them clear.

The idea seems to be very widespread that the "natural" motion of a planet around the Sun is in a circle, or that it is "more natural" for a planet to move in a circle than in any other curve. It is not easy to see precisely what "natural" means to those who use the word in this connection, but they evidently have some idea, doubtless poorly defined, for they imagine that it puz-

* Written at the suggestion of the Editor.

zles astronomers to explain why the planetary orbits are not circles.

What is "natural" and what is "not natural?" The fundamental principle which is the basis of all reasoning in the physical sciences, and in the intellectual and moral as well, is that every event follows an adequate cause, and that every cause (combination of simple causes) leads to a corresponding event. Of course, this is not so very deep from a philosophical point of view for philosophers say all that we know is that there is a sequence of events and that "adequate cause" has no meaning; nevertheless the conception is one of much value in practical life, and when it is thoroughly assimilated it will keep one from many foolish blunders. Granting the law of "cause and effect" there is no such thing as "natural" or "not natural;" the question is simply what causes are operating. One set of causes might lead to circular motion and another to something else.

It may be worth while to digress a moment on cause and effect. The universal experience of mankind has made the principle axiomatic, though we generally do not consciously formulate it. Nothing is beautiful or admirable which is not in conformity with this law. Think of architecture! Would anyone imagine a structure was beautiful if it were built of very strong material in such a way that it had the appearance of instability? How much more the Grecian column would appeal to him! Similarly, a novel cannot be great and effective unless it preserves a good balance between cause and effect, and acting is not splendid or powerful unless the actor does precisely what the circumstances demand. Thus a little analysis shows how deeply the principle has penetrated the subconsciousness of the race. Nevertheless, there are very numerous examples, even among intelligent people where it seems to have been lost from view. One only needs to mention the numerous superstitions respecting beginning work on Friday, the number thirteen, looking over one's shoulder at the Moon, fortune telling, etc., to illustrate the statement. All of these things are exactly on the same logical basis as the witchcraft beliefs of former times and the voodoo worship of the negroes, and are utterly unworthy of thinking people. More serious still are the common beliefs among certain individuals that the laws of health can be violated with impunity, or that a person recovers from an illness so that he is precisely the same as he would have been if he had not had it. These are errors which should perish.

In fact, everything is a cause of some subsequent event. Con-

sider a result of the law of gravitation. The force existing between two bodies depends upon their distance apart. If a person goes up from the surface of the Earth his attraction for it is altered, which to some very slight extent causes a change in its shape. A similar result is produced if he changes the position of his hand or a finger, not only in the Earth but also in a lesser degree in the Sun and every other heavenly body. It is believed that in every mental act there is some rearrangement of the atoms in the brain, and if it is true, it is perfectly certain for this reason that every thought, whether beautiful or ignoble, has an influence out to the remotest regions of the universe to which gravitation extends. The only advantage of pushing the principle to this extreme case is that it may be completely understood, and it must not be supposed that the statements above throw any light whatever on such subjects as telepathy.

The Problem of two Bodies.—Consider the motion of a planet around the Sun. Suppose that at a certain instant it is moving at right angles to the line joining it to the Sun. If it were subject to no force it would move in a straight line and would recede from the Sun, since its distance would be the hypothenuse of the right-angled triangle. This tendency to recede from the Sun, which may be called the *centrifugal acceleration*, is proportional to the square of the velocity at the instant in question. If the acceleration due to the Sun's attraction exactly balanced this centrifugal acceleration the planet would remain at the same distance from the Sun and would revolve around it in a circle. But the Sun's acceleration of the planet does not depend upon the motion of the latter; consequently if the velocity were greater than that just assumed the centrifugal acceleration would be so great that the planet's distance would increase, at least for a time. After a time there would be a component of the Sun's attraction opposed to the direction of motion of the planet and its velocity would be decreased until the centrifugal acceleration became equal to, and finally less than, the acceleration due to the Sun. Then the conditions would be reversed, and this would be repeated indefinitely unless the initial velocity exceeded a certain limit.

The precise curve described by the planet depends upon the way the Sun's attraction varies with the distance. Newton first proved that the orbit will be a conic section for all initial conditions if the force varies inversely as the square of the distance, and he also proved the converse. In this case the Sun will be in one of the foci of the conic. It follows from these theorems and Kepler's first two laws of planetary motions, which were de-

rived directly from the observations of Tycho Brahe, that the attraction of the Sun for a planet varies inversely as the square of its distance.

Kepler's third law leads to the conclusion that the acceleration of all the planets would be the same if they were all at the same distance. This is a matter of some interest for it might be supposed that perhaps different masses attract each other only if they contain the same elements. Under this hypothesis we would say that all bodies fall toward the Earth because the Earth contains in its interior large quantities of all the elements with which we are familiar, and we might suppose that such soft metals as gold and lead are heavier than hard metals such as iron simply because they are more abundant in the Earth's interior. Similarly, we would say the Sun attracts every planet because it contains the elements of which they all are constituted. Now, if this were the case the planets would move in conic sections but not in such a way that Kepler's third law would be fulfilled unless they all contained the different elements in precisely the same proportions, a supposition which seems very improbable in view of their widely different densities and physical conditions.

It follows from what has been said that if the planets had been started just right they would move in circles, except for influences other than the Sun's attraction. Why were they not started precisely in this way? There is no known reason why they should not have been, and on the contrary no known reason why they should have been. One might as well ask why the trees in a natural forest do not grow in straight rows or in circles, or why the clouds are not all spherical. There is no doubt that there are perfectly definite reasons, but the causes which have given rise to the present order of things are extremely remote and difficult to find. In the absence of any knowledge respecting these causes there is no occasion whatever for anyone to wonder that the planetary orbits are not circles. It would be just as reasonable to expect that all the orbits would have an eccentricity one forty-seventh as that it should be zero.

If the force of gravitation varied directly as the distance all of the planets would move in ellipses whose centers would be at the Sun, or more exactly, at the center of gravity of the whole system. This would be true taking into account not only the attraction of the Sun but also the mutual attractions of the planets. In this case the periods of all the planets would be exactly the same and one year would be precisely like every other

so far as it depends upon the revolutions of the planets. The planets and Moon would have constant positions with respect to the Sun as seen from the Earth. For example, the Moon might always be full and the inferior planets might be seen projected on the Sun's disc.

The Mutual Influences of the Planets.—The curious idea seems to be somewhat prevalent that the planets are distributed so that their mutual attractions prevent the collapse of the system, and that if a single one were removed the rest would soon be destroyed. This is an error which seems to have become current in the days when people believed that everything in the universe has been definitely arranged for the benefit of man. The fact is if a planet were removed everything would run along on the Earth so nearly as it does at present that no one but an astronomer or a careful observer of the sky would ever notice the difference. The planets effect the phenomena of every day life to an extremely slight extent, and there is absolutely no scientific basis for the prediction of human events from their configurations.

A question of the highest interest is whether or not the slight mutual influences of the planets will destroy in the lapse of time the present general configuration of the solar system. It is conceivable that the large planets may collide, or that part or all of them may be precipitated on the Sun, or that the eccentricities of their orbits may become so great that radical changes of seasons will result from their varying distances. Thus if the eccentricity of an orbit should become one-half the planet would be three times more distant at aphelion than at perihelion, and in the former case it would receive one-ninth as much heat and light as in the latter. A rigorous mathematical answer to this question is by no means easy. In discussing the matter it is convenient to suppose the planets are always moving in ellipses whose elements continually change. This is something like saying that a point which describes a circle always moves in a straight line whose direction continually changes. Indeed, this is the actual way the matter appears to our intuitions as we see when we attempt to think of what we mean by the velocity at any point in curved motion.

Now, if the planets move in ellipses whose elements continually change, the question is what changes will not destroy the present configuration of the system. The following conditions are compatible with what may be called *stability*, and the first three are necessary.

(1). The major axes must not vary except within comparatively narrow limits.

(2). The eccentricities must not vary except within comparatively narrow limits.

(3). The inclinations must not vary except within comparatively narrow limits.

(4). The longitudes of the nodes may change in any manner whatever.

(5). The longitudes of the perihelion points may change in any manner whatever.

A little more than a century ago Laplace and Lagrange developed general expressions for the elements of the planetary orbits, and the same fundamental methods are used at the present time. These expressions are infinite series in the masses of the planets, and in order that the stability of the system may be proved from them, it is necessary to show first that they converge and actually represent the elements for some interval of time; and secondly: that they vary only within narrow limits in the case of the major axes, the eccentricities, and the inclinations for all values of the time. The founders of celestial mechanics gave no proof of the first condition, and in discussing the second condition they considered only the first term of each of the infinite series.

Cauchy's epoch-making researches on the solutions of differential equations, which were published in 1842, show that the general method of solution is valid within sufficiently restricted time limits. The question of stability, therefore, reduces to that of the convergence and magnitude of the sums of the infinite series as the time, which occurs in the coefficients in an extremely complicated manner, increases without limit. No proof whatever has been given that they converge for very great intervals of time or that their sums are continually within any prescribed limits. Since the masses of the planets are very small compared to that of the Sun, which is taken as unity, the succeeding terms contain increasing powers of very small numbers, and since their coefficients and their sums are very small on the start they will be of slight importance for at least a considerable time. Consequently, a discussion of the coefficients of the first term shows quite approximately how the elements vary for a certain time which is doubtless very long from a human point of view. This discussion has been made in detail and shows that, so far as the first terms settle the question, the major axes oscillate around their present values with comparatively short period

changes; the inclinations and eccentricities oscillate around their present values with short period and very long period changes; the longitudes of the nodes and perihelia undergo short period oscillations and on the whole change indefinitely in one direction or the other. Consequently, so far as the first terms lead to any conclusions, they show that the system is stable.

Poisson has discussed the second terms of the series for the major axes and has shown that they are made up of two sorts of simple expressions; first, those which are purely periodic, and secondly those which are periodic but in which the magnitudes of the oscillations increase indefinitely with the time. Eginitis has more recently investigated the terms of the third order of the series for the major axes and he has found expressions in them which change indefinitely, though extremely slowly, with the time. Numerical results were given for the Earth and Saturn and it was found that the major axes of both of these planets are decreasing very slowly. An analysis, which leaves something to be desired regarding its rigor, shows that this decrease is not absolutely permanent, but that it is simply one phase of an extremely long oscillation.

What can legitimately be inferred from the investigations which have been made on this subject? Only this: unless there are other forces involved than those considered the general configuration of the solar system will remain much as it is at present for a long time, probably tens of thousands, or even millions, of years. The statements made in many excellent popular books that the stability of the solar system *for all time* has been proved is entirely too strong and has absolutely no logical foundation. The mathematical evidence is no better than that furnished by geology and biology, and one would scarcely draw such sweeping conclusions from the data furnished by these sciences.

It is worth while to insist for a moment that the mathematical discussions so far made are neutral on the question of stability. As has been remarked the so-called *secular* expressions, or those which vary indefinitely with the time, appear in the higher terms. One might think that this proves, granting the convergence for all values of the time, that the elements change indefinitely. But this is not necessarily so even though the strong concession respecting the convergency is made. For, consider sin mt. This expression never exceeds unity for any value of mt. It is expansible in the series

$$\sin mt = mt - \frac{m^3t^3}{6} + \ldots\ldots .$$

which converges for all values of t. If the right member alone were considered and the law of succession of the terms was not known it would apparently become indefinitely great with the time. In a similar manner the secular terms in the series for the elements of the planetary orbits *may* be the expansions of periodic terms which have been introduced in this manner because of the method of integration. Or, they may not be the expansions of simple periodic terms but their sum may oscillate between narrow limits for all values of the time. Or, the series may not converge, that is, not give the true values of the elements, except for limited values of the time. In the absence of any proof of the incorrectness of these three possibilities there is no basis for inferring the system is unstable.

Conversely, suppose the differential equations could be integrated, as Newcomb and others have shown they can be, in series all of whose terms contain only periodic expressions which are necessarily finite. This is by no means sufficient to insure the stability of the system. It would have to be shown in addition that these series actually represent the elements and that they converge for all values of the time. One might be inclined to infer that a series of terms which are all finite and built up of periodic expressions would always be finite, but the conclusion is not at all necessary as a simple example will show. Consider

$$\frac{a}{1 - c_1 \sin t - \sin \mu t} = a\,(1 + c_1 \sin t + \sin \mu t + \text{higher powers}).$$

Suppose c_1 is a small constant and μ a very small constant, as one-billionth. Then for all values of t not exceedingly great the expression is finite and oscillates around the value a, the terms involving μ being absolutely negligible. But when t equals 500,000,000 $\sin t = 0$, $\sin \mu t = 1$ and the expression becomes infinite and the series divergent.

The conclusion is that there is no proof of the permanent stability of the solar system, but the investigations do show that it will not undergo radical changes for a very long time. This is in no sense a reproach to those who have worked in these fields, for the subject is one of transcendental difficulty and their achievements have been most brilliant; it is rather a protest against the too sweeping conclusions of the commentators on their work. It may be that the problem is inherently impossible of solution depending as it does upon observations which are not indefinitely exact. For example, suppose it depends upon the commensurability or incommensurability of the mean motions;

within the limits of accuracy of the observations it would be possible to satisfy either hypothesis in an infinity of ways and there would be no means of distinguishing which should be taken.

Hypotheses. The enumeration of the hypotheses which are at the basis of the investigations which have been discussed has been omitted until the present so as to take up the whole subject of assumptions at one time. In all the researches respecting the stability of the solar system the explicit hypotheses are made that all the members of the system attract each other according to the Newtonian law as though their masses were concentrated at their respective centers, that there are no other forces at work than the mutual attraction of the spheres, and that the mean motions are all incommensurable. Neither of the first two conditions is satisfied and as has been remarked it will never be possible to determine whether the third is or not. The first fails because the Sun and planets are not exactly spheres which are homogeneous in concentric layers, and the second because there are magnetic forces, tidal forces, resistances from meteors, and probably attractions by the stars.

Let us enumerate some of the possibilities not taken into account in the researches on the stability of the system. It is not known that the law of the inverse squares expresses *exactly* the way gravitation varies. We know that most of the celestial phenomena can be explained under it for the interval of time covered by our observations, but the true law may differ from it to so slight an extent as to have not yet led to appreciable results but in such a way as to doom the system to ultimate destruction. There are certain phenomena in the kinetic theory of gases which point to the existences of forces among molecules varying inversely as the fourth power of the distances, and it may be that adhesion, cohesion and chemical affinity are different manifestations of the same force under different circumstances of distance. If the actual law were

$$f = c_1 \frac{m_1 m_2}{r^2} + c_2 \frac{m_1 m_2}{r^3} + \ldots\ldots$$

the coefficients $c_1, c_2, \ldots\ldots$ might have such values that the first term alone would be sensible, except after an extremely long time, for such distances as are involved in astronomical problems; for another order of distances, perhaps such as are involved in the phenomena of cohesion, the second term would be the dominant one, and the third in chemical reactions, etc. It may be that the planets are retarded to some extent by the ether. It

may be that matter is slowly wearing out. For example, if an atom is a vortex ring in the ether, as Lord Kelvin supposed it might be, it may suffer some slight resistance which in the course of immense ages will destroy it. It has been found more recently from the researches of J. J. Thompson and others that the atoms are very complex affairs, being made up from a thousand to hundreds of thousands of electrons which under certain circumstances may break away from the groups to which they belong. In this way ordinary matter may become radically changed. On the contrary it is not impossible, or perhaps even improbable that what we ordinarily call matter is developing from some other state in certain other parts of the universe. And it may be that there are regions where the ether does not exist, for example surrounding the whole visible universe. Since light cannot cross an etherless space this would account for the seeming finiteness of the material world. There may be forces whose effects are of the utmost importance in the long run which are at present entirely unsuspected; the fact that known phenomena can be explained without them is not at all conclusive evidence against their existence.

The fundamental difficulty in our speculations is that we are limited by a narrow experience extending over a very brief period. The lifetime of a man seems fairly long, and the epoch when Troy was beseiged, or when the Pharaohs piled up the pyramids in the valley of the Nile, or when our Aryan ancestors separated on the high plateaus of Asia seems extremely remote, but these intervals are only moments compared to the immense periods required for geological evolution and the enormously greater ones consumed in the development of worlds from widely extended nebulous masses. We recognize the existence of only those forces whose immediate consequences are appreciable and it may be that those whose effects are yet unseen are really of the highest importance. A little creature whose life extended over only two or three hours of a summer's day might be led, if he were sufficiently endowed with intelligence, to infer that passing clouds were the chief influences at work in changing the climate, instead of perceiving that the Sun's slow motion across the sky would bring on the night and its southward motion the winter.

We may epitomize by saying that there is no such thing as "natural" motion of the planets, but that they move in obedience to gravitation in orbits which are nearly strict ellipses with the Sun at a focus; that they are so nearly independent that no ordinarily noticeable change would take place if one were re-

moved; that the mathematical difficulties are such that we can not yet say whether, under the hypothesis of the Newtonian force and no others, the system is permanently stable or not, although we can affirm that it will remain in its present general condition for a long time; and finally that our limitations are such that we can never be sure that we have the data necessary for the discussion of the question of permanent stability.

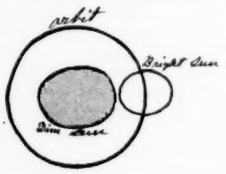
THE UNIVERSITY OF CHICAGO.

STARS THAT PERIODICALLY GLOW AND FADE.

ROSE O'HALLORAN.

FOR POPULAR ASTRONOMY.

In cosmical manifestations, nothing is more real than the capacity of about 600 stars to alternately increase and decrease in apparent magnitude. A few glow and fade very noticeably without magnifying power, but the greater number are telescopic orbs strewn among the changeless millions. The variable stellar sun may be whiter than our Sun, or it may be red, but most frequently is of orange hue. The details of fluctuation are diverse enough to necessitate several theories as to cause.



COMPANION SUNS FORMING BETA LYRÆ.

The following theory of Professor G. W. Myers of Illinois closely suits the changes of Beta in the Lyræ, a white star whose light ranges twice between third and fourth magnitude in about thirteen days. To vivify the idea of what occurs in remote depths, we may fancy it of Sun size, and closely adjacent to it a smaller and brighter sun in the act of passing round it, both being slightly ellipsoidal in form.

The luminous discs thus side by side would create a maximum of radiance; but in three and one-fourth days the smaller sun progressing in its orbit passes behind the less luminous companion, thus causing a marked decrease in light. This phase gradually passing away, a second maximum occurs in three-fourths more days, as the full discs again appear side by side to be succeeded by a second but lesser minimum as the minor orb passes in front of the duller orb, the disc then superposed being the brighter of the two.

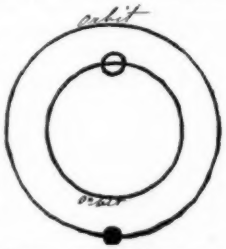
A series of these interesting phases are thus completed on the thirteenth day. Different forms of this eclipse theory are applied

to Algol and nearly a score of stars whose marked punctuality of period and other peculiarities indicate the co-operation of revolving bodies. In most of these cases a dark satellite crossing the disc of the luminous orb probably causes the brief decline in light which is sharply defined.

Spectacularly, a partial eclipse of our own Sun fairly illustrates this occurrence, but that Algol's satellite is very close to it and of nearly equal size. Eclipse stars complete their round of change in short periods amounting only to a few hours, days or weeks. In such orbs there is of course no innate decline of lustre; but a different hypothesis is required for other variables of short period and for all those of long period. The greater number of the latter complete their cycles of change in from 200 to 400 days.

Large irregularities as to time and variation, a more gradual change of phase and also a change of color and spectra are among the chief evidence that in their case a real difference of condition takes place.

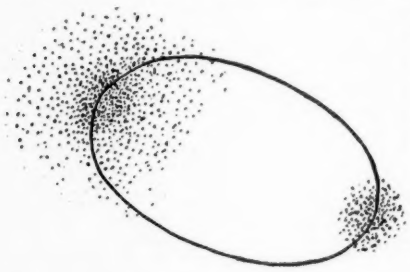
Whether the increase that centriples the glow has the same cause as that which merely doubles or trebles it is an unsettled question. One theory again invokes the co-operation of a dark companion but in an entirely different manner. It obstructs our view of the stellar sun little if at all, and instead of close companionship an elliptical orbit brings them alternately near and far apart. By increased attraction enormous tides are thus in operation on the vaporous body during a large portion of its revolution. This hypothesis accounts well for the paling tints of red variables at greatest magnitude, for if we picture a sun crimsoned by its own outer envelope of absorbing vapor the scattering effect of furrowing billows is easily imagined, while, crested with the intense inner glow they create a spectrum of bright lines. Plassmann, a German scientist, is the most conspicuous exponent of this tidal theory which has commanded much favorable attention. The attraction of more than one dark companion aids explanation by accounting for occasional irregularities in the phenomena. Sir William Huggins and Dr. Wilsing extend this theory to new stars, the chief difference being that the object of tidal effects in this case was previously in the first stage of invisibility, its surface having cooled sufficiently to form a thin crust. When this is rent the glowing nucleus is endowed with a brief term of renewed Sun life but if



ALGOL AND ITS DARK SATELLITE.

such rejuvenescence arises from internal causes, as yet astrophysics is unable to explain the irruptive process.

Another possible cause of stellar change, first suggested by Newton, is collision. The various forms of matter throughout the universe leave much scope for diversity in this explanation, but an encounter of meteor swarms, so effectively advanced by Sir Norman Lockyer as a solution of all stellar variability, is the most remarkable. According to this view, a comparatively small swarm at the curve of its orbit nearest to a larger swarm round which it revolves, collides more or less with the components of the latter, an increase of light being the inevitable result.



METEOR SWARMS DURING MINIMUM OF VARIABLE STARS.

Its amount and duration would depend respectively on the density and extent of the swarms, a periodic dimness gradually setting in as the effect subsided. Irregularity of period is, however, difficult of explanation in this interesting hypothesis. Our own Sun, the one self-luminous orb whose surface can be distinctly studied, also gives in its eleven year sunspot cycle a faint clue as to what may be occurring on a stupendous scale when stellar suns grow dim as if shrouded in gloom. Dissimilar though the extent of the results, sunspots cannot be ignored in the study of this phenomena, for they alone constitute the one solitary evidence of a self-darkening process. It is likewise periodic and slightly irregular. The imperceptible diminution of sunlight during sunspot years would need to be increased five hundred fold to compare with stellar decline, but nature is partial to creations similar in kind though on a different scale; thus the zephyr and the tornado spring from the same atmospheric source. If, as some physicists suppose, sunspots are a down rush of meteors when at the perihelion of their orbit, then denser swarms is the chief assumption required for a reasonable explanation of the mystery. Many scientists, however, think that the increase of coronal rays frequently noticed when spots are most numerous may correspond with the maximum radiance of a variable star, the dimness being overbalanced by the accompanying extensions of luminosity. No investigation is so productive as that which is guarded by a keen discernment of discordant developments.

Though for centuries stellar variability has been known to exist, it is only within the last fifty years that valuable data have been available, and it is less than half that time since Chandler, Pickering and other eminent astronomers disentangled the conflicting testimony of the variables, classified results and cleared the way for a complete solution. Meanwhile, the mystic 600 with all their incompatibilities persistently wax and wane, creating urgent demand for accurate and continued research in this important branch of astronomy.

ON JOVIAN PHENOMENA.

G. W. HOUGH.

FOR POPULAR ASTRONOMY.

In the April number of POPULAR ASTRONOMY Mr. A. Stanley Williams has taken issue on two points pertaining to Jovian phenomena.

1st. The relative value of micrometer measures and eye estimates.

2d. Constant currents on the surface of the planet.

I had presumed that the relative accuracy of micrometer measures and eye estimates for objects in the planet Jupiter had been so clearly explained that there was no longer any ground for argument.

Mr. Williams has been a careful observer of the planet Jupiter for many years and his observations are excellent for the method he employs. An eye estimate or transit is the result of a single observation. On the contrary when the micrometer is used we have the mean value for a number of observations. If we admit that an eye estimate is equal in value to a micrometer measure, the mean of ten such measures would have three times the precision of a single one. I have previously shown that one set of four micrometer measures will give the time of transit with a *mean* error, not probable error, of less than one minute of time.

If the personal equation for micrometer work should be as much as the mean error, we would still find the total error, far within the limits assigned to eye estimates.

Mr. Williams' illustration of pairs of double stars of one second distance, it seems to me has no bearing whatever on the problem under discussion.

One may bisect by estimation a bar one-tenth of an inch in length, possibly within 1/500 of an inch, but one cannot bisect a

bar one foot in length to the same degree of precision. In observations on Jupiter we have a space of more than 40″ of arc to bisect; a bisection of such a distance by estimation within one second of arc would be good work. That would correspond to a mean error of 2.7 minutes on the time of passage over the central meridian of the disk. If Mr. Williams will take the trouble to ascertain the mean error for some of the best observers I think he will acknowledge the correctness of my statement. For such an investigation all the observations made by the observer during the opposition should be used and not one particular set.

It was not my intention to criticise or belittle the work of those who are not provided with driving clock and micrometer. They can and do make observations which are of value in the interpretation of phenomena seen in the surface of the planet.

On the contrary when an instrument is equipped for micrometer work it should be used in order to secure the greatest precision possible.

Astronomers familiar with measures of precision have determined the errors incident for eye estimates on the planet Jupiter not as a matter for controversy but to arrive at the truth.

Dr. Schmidt, *A. N.* 2342 and 2410 found his mean error for the red spot ± 2.6 min. Maximum error depending on the hour angle of the planet 7 minutes. Extreme range in personal equation for different observers 9 minutes.

Dr. Lohse, Astr--Phy. Obs. Potsdam, No. 9. For the red spot in 1880-81 for different sets of observations, mean error ± $1^m.9$ to ± $3^m.6$. Other spots ± $2^m.8$ to ± 6^m. In every line of astronomical research any advance in our knowledge will depend in a great measure on the precision of the observations. Hence whenever practicable the best method should be employed to secure such observations.

With regard to the second topic "Constant Currents:" I would gladly accept any hypothesis which would approximately satisfy our observations. In the table of rotation periods given in POPULAR ASTRONOMY 104 for the south equatorial current we find an extreme range of 35 seconds on the rotation period and a range of 11.6 seconds during one opposition.

I do not see how any one can draw any legitimate conclusion from such data.

More than twenty years ago I showed that the observations of the great red spot even for one opposition could only be satisfied by making the rotation period a function of the time and subsequently showed that variable motion was true for all spots.

The great red spot, according to the researches of Mr. Denning, has a variable rate of drift in longitude corresponding to the rotation periods $9^h\ 56^m$ to $9^h\ 55^m\ 33^s$. There is apparently no constant current in this latitude.

In 1896-97-98 a black spot in north latitude indicated a decided change in the rotation period during the three years:

Date.	Rotation Period.	Dist. N.	Jovicentric Lat.
		″	°
1896	9 52 00.4	+ 8.4	25.9
97	9 55 59.7	+ 8.2	25.2
98	9 55 52.0	+ 7.9	24.2

In this case the spot drifted in latitude 0″.5 or 1°.7.

Whether a change in rotation period of a spot is due to, or connected with its change in latitude cannot now be decided, but it is not unreasonable to suppose that its drift in longitude may be influenced by its drift in latitude. For a critical study of the complicated phenomena brought to our notice, we must have observations of precision for longitude, latitude and magnitude.

One second of arc on the surface of Jupiter is equal to 2300 miles. Two spots or markings in the same longitude and differing only 0″.5 in latitude, would be more than 1000 miles apart, and hence might have different rates of proper motions on the surface.

According to our present knowledge we cannot say that in any latitude the motion of an object on the surface is constant.

DEARBORN OBSERVATORY, Northwestern University,
May 4, 1903.

DOUBLE STARS.*

1. *A General Catalogue of 1290 Double Stars discovered from 1871 to 1899.* By S. W. BURNHAM. Publications of the Yerkes Observatory. Vol. I. Chicago: 1900.

2. *Reference Catalogue of Southern Double Stars.* Compiled by R. T. A. INNES. Annals of the Royal Observatory, Cape of Good Hope. Vol. II. Part II. Edinburgh: 1899.

3. *Micrometrical Observations of the Double Stars discovered at Pulkowa.* By W. J. HUSSEY. Publications of the Lick Observatory. Vol. V. Sacramento: 1901.

4. *Researches on the Evolution of the Stellar Systems.* By T. J. J. SEE, Ph. D. Lynn, U. S. A.: 1896.

5. *Traité d'Astronomie Stellaire.* Par Ch. André. Deuxième Partie. Étoiles Doubles et Multiples. Paris: 1900.

* Reprinted from the Edinburgh Review, Jan. 1903.

6. *Discoveries and Measures of Double and Multiple Stars in the Southern Hemisphere.* By T. J. J. See. Astronomical Journal, Nos. 431-432. Boston: 1898.

"The making of an hypothesis is not the discovery of a truth," Lord Brougham wrote one hundred years ago in the pages of this Journal. And the maxim is worth remembering, notwithstanding the unwisdom of its application. For it was invented to discredit "the wild optical theory of vibrations," experimental proofs of which had then recently been alleged by Dr. Thomas Young. It is not our purpose to re-open that antiquated discussion. As the case showed to contemporary opinion, "much might be said on both sides," in the words of Sir Roger de Coverley's pacificatory judgment on the dispute between Will Wimble and Tom Touchy. Young was substantially in the right, although his demonstrations were faulty; Brougam blundered presumptuously in the midst of an ostensible dialectical triumph.

Young's Bakerian lecture on the "Theory of Light and Colors," containing the first rudimentary attempt to explain diffraction-fringes by "interference," and to establish on this basis the undulatory hypothesis of light, appeared side by side with Sir William Herschel's announcement of the mutual revolutions of double stars in the "Philosophical Transactions" for 1802. The two investigations seemed disconnected; only superhuman sagacity might have discerned any trace of an auxiliary relation between the branches of knowledge they respectively dealt with; and Brougham would have been the keenest of scoffers at so far-fetched and preposterous a notion as that of its future establishment. Yet it has come to pass that, by a subtle affection of the ethereal waves constituting light, stellar systems have been numerously revealed, possibly in an embryonic condition, and certainly inaccessible to present or future telescopic observation. These extraordinary discoveries have served essentially to modify our views of the universe. But we must not anticipate.

The advance of double-star astronomy, during the century which has elapsed since its effective foundation, has taken a course equally unexpected and characteristic. By its means a link has been forged between the old and the new astronomy—between the astronomy of the telescope and micrometer and the astronomy of the spectroscope and the camera. Astrophysical methods come in with singular felicity just where astrometrical methods cease to be available. And the alliance reacts advantageously upon both kinds of research, imparting to the new the accuracy of the old, and to the old some of the flexibility of the new.

Pairs of stars were at first thought to result merely through the hazard of distribution. Indistinctly, and with hesitation, the idea of their forming genuine couples was enunciated in 1777 by Father Christian Mayer, the Jesuit court-astronomer of Mannheim, and Lalande gave expression to current views in rejecting it as incredible. Mayer, too, set the example of collecting and expressly observing such objects. But his attempts were almost obliterated by the achievements of his immediate successor. Herschel undertook the research with the ulterior design of a parallax-campaign. He thought—as Galileo had thought—that since stars apparently adjacent in the sky were presumably separated by an indefinitely vast real interval of space, one might supply a convenient fixed point for measuring the annual perspective shift of its companion, due to the wheeling of the Earth in its orbit around the Sun. His expectation, however, was in this respect disappointed. Double stars, to begin with, proved far too numerous to be the outcome of chance. Herschel's powerful telescopes, employed with his matchless skill, divided hundreds of stars, previously held to be single, into pairs of globes, just islanded by a fine strait of darkness. A strait of darkness, barely to be seen, yet signifying so much! Already, in 1784, the Reverend John Michell, still more formally than in 1767,* denied the possibility of casual juxtaposition. Stars strewn broadcast, however profusely, could not have become contiguously disposed in the multitude of cases to be accounted for. The doctrine of probabilities alone placed it beyond doubt, he considered, that most, if not all, of the multiple objects detected by Herschel "are systems of stars" mutually, revolving under the influence of gravitation.† Herschel's long-sustained observations finally verified the forecast. On July 1, 1802, he declared "the multiplied phenomena of double-stars" to depend upon a general law of nature, and promised evidence, which was shortly afterwards amply forth-coming, showing in many of them a progressive change of relative situation indicative of periodical circulation one round the other.‡

The communication made a profound impression, which the efflux of time and the growth of knowledge have helped to deepen and strengthen. By the discovery of binary stars, unification of the cosmos in one respect, differentiation in others were brought about. The law of force governing the planetary scheme

* *Phil. Trans.*, Vol. LVII, p. 249.

† *Phil. Trans.*, Vol. LXXIV. p. 76.

‡ *Ibid.*, Vol. XCII, p. 486.

received an indefinite extension, while constructive variety was at the same time perceived to have a boundlessly wide scope. The sidereal world was at last included within the range of physical enquiries, yet of physical enquiries perhaps transcending the limitations of terrestrial experience. That suns may form part of systems in which they are not supreme is a fact of immeasurable significance. Through its disclosure our ideas of the purposes they are designed to fulfill have been in a measure confounded. We learn from it that our sun and his family are no universal model—that other suns have other relationships; and the trammels of analogy being thus loosened, the imagination is set free to expatiate in wide fields of speculative thought.

Like all disclosures of real moment, Herschel's of revolving star-pairs was only a beginning. One man made it; generations of men may spend their lives in working out its consequences. One of the most direct and practical has been that of stimulating telescopic improvement. Double stars are test objects of graduated difficulty. Specimens of all varieties are to be found down to and far beyond the limit of optical resolving power. The series does not terminate; pairs more and more delicate come into view as larger and finer telescopes are brought to bear upon them. Their efficaciousness depends primarily upon aperture; with equally good definition the greatest objectives will divide the closest stars; each gain in size brings with it the potential disclosure of stellar pairs inaccessible to minor instruments. Now just these are usually the most interesting, because they are the most apt to be in rapid revolution. Their detection is hence an object of ambition to the best observers, who, in their turn, strain the utmost resources of optical art to supply them with the needful weapons. Thus supreme telescopic excellence is a *sine quâ non* of progress in this branch. How far it has yet been attained may be gathered from one simple statement. Stars can be clearly divided with the Lick thirty-six inch refractor when the interval between the components does not exceed one-tenth of a second, or the breadth of a silken fibre placed at a distance of thirty-five feet from the eye. But Herschel's most compressed couples were about ten times further apart, so that we may safely assert telescopic effectiveness in this respect to have decupled within a century. Is there a limit to it? We believe there is, and that the limit has nearly been reached; yet the imminent sterility of such researches need not therefore be apprehended. A subtler mode of prosecuting them than that of direct star-gazing comes, with singular appropriateness into play where the latter breaks down.

The reactive effects upon the technique of astronomy of making acquaintance with physical double stars were, however, incomparably less important than its theoretical results. The range of celestial mechanics was thereby indefinitely widened. The principles of that sublime science were shown to be valid to the remotest boundary of star-filled space, while endless possibilities of their exemplification in novel cases, demanding for their adequate treatment fresh expedients of abstruse invention, seemed to open up. Not that any demonstration was provided off-hand for the identity of the compulsive forces holding the stars and the planets in their orbits; but the presumption that gravity dominated all equally was irresistible, and has since been so fully justified that only a pedant or a purist can any longer pretend to a doubt on the subject. And so a science of the cosmos came to be established, for exact knowledge begins with the recognition of law.

Herschel estimated the periods, but did not attempt formally to calculate the orbits of any of his stars. This was successfully essayed by Savary in 1827. The subject of his experiment was ξ Ursæ Majoris, a bright and fairly obvious pair, registered by Herschel in 1781, since when it has performed two complete revolutions in approximate conformity to the rule of the road laid down for it by the French geometer. The line of enquiry he struck out has many ramifications; it leads to sundry problems, not even yet ripe for attack; but the initial one of deducing, from the projected representation of an ellipse, the ellipse itself, has been effectively solved. Stellar orbits are presented to us in every variety of position and in all degrees of fore-shortening. Luckily, however, an ellipse viewed in perspective is still an ellipse—apart from the extreme cases when it shows as a circle or straight line; while Kepler's law of the description of equal areas in equal times holds good for the apparent as for the real path. The main difficulty besetting the computation of orbits is, in fact, not of a mathematical, but of an observational kind. The most exquisitely refined measurements are affected by some uncertainties; and the scale of the fairy rounds traced out by the stars in the sky is so minute that infinitesimal errors introduce very material inaccuracies into the diagrams graphically portraying them. The task is then always onerous, and often futile, of completing a stellar ellipse from the section obtained by plotting observations. Even though the section be of considerable extent, the stars may nevertheless, as months or years go on, deviate widely from their predicted places, closing in upon or

running out from each other after a wholly unlooked-for fashion. But if they disavow what is called the "apparent" orbit ascribed to them on the strength of their actually determined, successive places, still less can any dependence be put on the real, though unseen, orbit derived, so to speak, at second hand. In this matter there can be no hurrying to conclusions. The surest way of learning how a given pair of stars revolve is patiently to watch the process. When they have regained their starting-point, their periodic time is given *ipso facto*, and the other elements of their motion can usually be fixed with tolerable certainty. They must almost literally be seen to be known. Thus, few stars with periods longer than a hundred years traverse reliably computed orbits, and about forty visual pairs reach this standard of rapidity. By a liberal estimate it might be said that fifty binaries are well under the control of calculation.

Let us see what kind of systems they form. As might have been expected, the plan of their combinations is immensely varied; and this, indeed, it is which gives them such peculiar interest. Each pair might be set apart for separate study; chapters might be written on the history, dynamical relations, and physical state of some among them. None is more intimately known than the superb southern binary α Centauri. Since its discovery by Father Richaud at Pondicherry in 1689 it has finished two circuits, and is more than half through a third. The period, according to Dr. See's trustworthy calculations, is eighty-one years. The orbit described is an elongated ellipse, of very unusual apparent dimensions. Its seeming bigness, however, is merely a consequence of the star's comparative vicinity. We have no other such near neighbor in space. Light travels thence to our eyes in four years and four months, although the more brilliant rays of Sirius spend on their journey above twice that interval. The distances of binary stars are data of special importance. Upon them depends the scale of each system; and the scale gives the velocity, consequently the mass, of the revolving bodies. In the case of α Centauri all these particulars have been ascertained. At "periastron," their closest mutual approach, the connected stars are separated by a gap of space slightly exceeding that between Saturn and the Sun, while forty years later, they digress to far beyond the distance of Neptune. Their joint mass amounts to twice that of our Sun, and it has further been determined that the deviations of each from a straight line as it pursues its way across the sphere are sensibly of the same amplitude, showing that one star deflects the other just as much as it is itself de-

flected, which is equivalent to the statement that they possess the same gravitative power.* Their orbits, accordingly, are not only similar in shape, but of equal dimensions. The bodies traversing them are equally mobile; neither clings to the hub of the wheel, like our own central luminary which is sluggish because of its preponderance. Both gyrate round the empty focus common to their oppositely extended, oval paths, slackening in speed and accelerating together, so as always to be at corresponding but contrary points in those paths. Their movements, that is to say, are at each instant, equal and opposite. Revolving stars must, indeed, always travel in diametrically opposed directions, though not necessarily at the same speed. Velocity follows the inverse proportion of mass; and the quality of matter in a system is not as an invariable, or even as a very general, rule shared impartially between its members. The fact of its being so, in the case of α Centauri, is rendered more noteworthy by luminous disparity. One of the stars sends forth fully thrice the light of its companion. The dissimilar quality of their absorbing atmospheres partially accounts for this difference. The dimmer star is also the yellower, rays of the shortest wave-lengths being predominantly intercepted by the vaporous layers encompassing the photosphere. The photosphere itself may also be deficient in brilliancy, but of this we have no direct proof. The fact is, however, patent that two stars, equal in mass, contemporaneous, it is safe to assert, in origin, and closely analogous in chemical constitution, are yet markedly disparate in light-power. Both are of the solar type, but the deeper hue of the companion corresponds to a perceptible advance towards the spectral stage reached by red stars like Antares. The chief member of the pair in Centaur has been singled out by Sir David Gill as an exact and for purposes of stellar comparison, most serviceable model of our own Sun. The Cape photographs show their complete spectral identity, and this argues, for bodies not differing in mass, equality in mean density and areal brilliancy. A reasonable certitude is, in short, afforded that α Centauri is precisely such another sun as that which smiles through the tears of our skies; and the two might exchange places without disarrangement to their respective systems or disturbance to terrestrial meteorology.

It is scarcely likely that the stars of α Centauri form a barely dual combination. We may be sure that they have further at-

* Their relative masses were found by Mr. A. W. Roberts, in 1895, to be as 51 to 49. *Astronomische Nachrichten*, No. 3,313; *Observatory*, Vol. XVIII, p. 405.

tendants, dark or bright. If dark, their presence could only be divined by the perturbations it might produce, and none are suspected. Nor could planets, on the modest scale of the Earth or Mars, still less the brief blaze of a comet, become in any way discernible to spectators situated as we are. Yet the pair may not, for all that, be wholly isolated. In the summer of 1898 two very small stars, of about the eleventh magnitude, were picked up respectively by Mr. Innes and Mr. Lunt, both of the Cape Observatory, in suspicious vicinity to the great binary; and the possibility that they may be inseparably attached to it, and may act as its escort through space, has been adverted to by Mr. Innes in his valuable "Reference Catalogue," the title of which is quoted at the head of this article. The truth of the matter can be readily ascertained, since the large proper motion of α Centauri, which must be shared by objects belonging to its cortège, will decisively and at once test the reality of an imputed connexion. Now, is it shared by the little stars located four years ago? Their careful re-measurement next summer would answer the question. If so, the two brilliant and the two faint stars constitute a system, the structural nature of which will offer a problem of profound interest. The outlying stars may be individually attached, each to one of the brilliant orbs; or both may be satellites of the large pair regarded as a joint centre of attraction. In either case they should be insignificant in size, or nearly devoid of lustre. Not impossibly they shine wholly by reflecting the light of their primaries. Until we are assured of their dependent status, however, speculation on this subject would be futile. We can only hope that southern observers will make haste to gratify the curiosity they have excited.

The binary in Centaur has hitherto appeared to be one of the least complex of stellar systems; many other are of far more intricate construction. Triplets and quartettes were not rare in Herschel's lists, and they have been disclosed of late in astonishing abundance. A remarkable proportion of Mr. Burnham's difficult pairs represent, not the beginning, but a continuation of the resolving process. They are members of previously known, wide couples, which under stringent optical compulsion, avowed the unsuspected secret of their compound nature.

The mention of Mr. Burnham's name almost compels a brief digression. Although an amateur, he has done more to quicken progress in a highly technical branch of astronomy than anyone born during the last century. He began life as a stenographer in Chicago; then, in 1861, visited London, and bought a cheap tele-

scope. It was indeed little better than a plaything; but the use of it evoked latent proclivities, intensified by an interview with Alvan G. Clark, who fortunately halted at Chicago on his return from observing the Iowa eclipse of August 7, 1869. The upshot was the construction of an exquisite six-inch refractor, armed with which Mr. Burnham entered upon a unique career of discovery. He was unable to explain how the course it actually took was impressed upon it. The specialization of his work "came about naturally," he tells us, "without any effort or direction upon my part."* His preference for double stars, almost exclusive from the first, grew keener with success. Unusual acuteness of sight, an alert brain, a sagacious judgment, conspired to crowd his observing-books with choice trophies of exploration. As he labored each day in the Government court house, his anticipatory thoughts must often have flown to the back-yard where the six-inch stood awaiting the night. The long, lonely hours spent there were vivified by strange joys. The division of a star after insistent looking is a performance comparable, at any rate, to hitting the bull's-eye at a thousand yards—always a critical, often a triumphant achievement. Mr. Burnham's first catalogue of double stars, published in 1873, contained eighty-one new pairs; his last, the title of which is included among our headings, comprises 1,290. Not all of these, however, were found in the Chicago back-yard. During the twenty-seven years over which the record extends, he has been able to employ some of the largest and finest instruments in the world—the Dearborn 18½-inch achromatic, the 16-inch of the Washburn Observatory, the incomparable and incomparably situated 36-inch on Mount Hamilton, and latterly the Yerkes 40-inch, surpassed in size, if scarcely rivalled in perfection, by the colossal "siderostat" of the Palais d'Optique in Paris. He has probably never measured a star with a reflecting telescope, while Herschel similarly eschewed refractors; and the contrast is instructive as regards the history and vicissitudes of the two chief telescopic species. Mr. Burnham is now permanently attached to the Yerkes Observatory, although he continues to discharge legal functions at Chicago; and between Williams Bay and the city by Lake Michigan there is a stretch of prairie seventy-five miles wide. Quasi-ubiquity is implied, and the cost of attaining it is heavy to human nerves and brain.

Mr. Burnham's example revived the waning zeal of double-star

* Introduction to General Catalogue, p. VIII.

investigators by the demonstration it supplied that the ground, far from having degenerated into barrenness, as some began to fear, was still of unexhausted, and probably of inexhaustible, fertility. Not so much the quantity as the quality of his detections roused expert admiration. Nearly all were difficult; many, if described beforehand, might have been deemed impossible. The circumstance that five of these barely divisible pairs have completed each a revolution since their discovery emphatically illustrates their importance to physical theory; for, once the period of a star becomes known, much further information about it is sure to follow.

The catalogue we are now considering includes no fewer than 133 examples of the further analysis of pairs recorded in earlier lists. More than one-tenth of its total entries, that is to say, "is made up of previously known doubles, where one of the components has been again divided, or a much nearer star added to the system." Triple and quadruple combinations have in this way been numerously disclosed. They are of great variety, but a coupled arrangement predominates. Two pairs revolve round each other, or rather show an incipient tendency to do so, for the movements of such complex systems develop with extreme slowness. In other cases, a close pair, itself in revolution, plays the part of satellite to an apparently single star, or a single star circuits a duplex primary. Thus, there are commonly wheels within wheels. Each part of the mechanism is self-sustaining, although subordinate. Stellar systems composed, like an orrery, of one central body and many coördinate dependents, are rare or non-existent.

Already, in 1779, Herschel took note of ϵ Lyræ as a "double double star." The pairs are indeed so bright and so far apart as to be distinguishable by exceptionally sharp eyes, and a small telescope will further show each to be again compound. A similar plan of construction is carried out on a reduced scale in ν Scorpii. Reduction of scale, however, only enhances the interest of multiple stars, since it improves the prospect of gaining speedy insight into their dynamical relations. The original division of ν Scorpii was effected by Herschel in 1782. He found it to consist of a fourth and a seventh magnitude star separated by a considerable gap of space (41″ by Barnard's measures in 1897). Then, in 1846, at Cincinnati, the companion split up under Mitchell's scrutiny, and in 1874 the primary under Burnham's into beautiful close pairs. And all, though they show as yet no unequivocal signs of interstitial movement, undoubtedly,

as Mr. Burnham says, since they drift onward together, "form one vast quadruple system." The fact is of high significance that their proper motion is common likewise to several fairly conspicuous neighboring stars.* A complex nebulous area, disclosed in Professor Barnard's photographs, surrounds the group, which may, nevertheless, be merely projected visually upon it.

A stellar triplet of particular interest is met with in κ Pegasi, a fourth magnitude star with a faint attendant noted by Struve in 1828. In 1880, moreover, Burnham divided the primary into an excessively close couple, revolving so rapidly as to have now almost completed its second observed circuit. The period of 11.4 years was, in fact, until quite recently, the shortest attributed to any binary within telescopic range. Struve's companion must be, in some manner, attached to the system, since it travels with it. Such instances are not uncommon. Small stars frequently seem to be *towed along* by great ones, like row-boats by steamers. Their status, both physical and dynamical, constitutes one of the many curious and far-reaching problems encountered in the study of double stars.

A case of drift still more remarkable than that of κ Pegasi has been adverted to by Mr. Innes.† Here four stars, grouped two and two together, are borne over the sphere by a wide and swift current of motion. One of them is κ Toucani, of easy naked-eye visibility, supplied by Sir John Herschel in 1834 with a purplish satellite. The other is a neat pair discovered by Mr. Innes himself. Although certainly connected, the two binaries (as they may safely be called) are comparatively remote. The interval between them is actually 118 times wider than that separating γ Toucani from its client-star. It represents probably a real gulf of some billions of miles; but data are wanting for more than a conjectural estate of its linear value.

Dr. See, who discovered 500 southern double stars with the Lowell 24-inch refractor at Mexico in 1896-7, was much struck with the "dull lustre" shown by many of their satellites, some of which appeared puce, others plum-colored. Indeed, the frequent inclusion by stellar systems of dusky or even wholly obscure members is one of their unexpected characteristics. Close upon seventy years ago, Bessel perceived a lack of uniformity in the proper motion of Sirius, and his suspicions extended soon afterwards to Procyon, the lesser Dog-star. Both these radiant objects pursue, in fact, undulating tracks across the sky. They

* *Monthly Notices*, Vol. LVII, p. 456; Reference Cat., p. 10A.

† Innes, Reference Catalogue, p. 157A.

sway alternately to one side and the other, as if pulled by an accompanying attractive mass. Bessel's prediction of their binary nature, however, had to wait long for verification, which the scant luminosity of their companions rendered most difficult to procure. That of Sirius was found by Alvan G. Clark in 1862, as a tenth-magnitude star which avers its identity with the theoretical body by circulating duly in a period of half-a-century. Yet though constructed on the scale of a sun, it would seem to be imperfectly organized for shining. Of just the solar massiveness, it possesses no more than 1/1700 the solar luminosity. And the disparity is the more astonishing from the contrast of its state with that of its primary, which gravitates as two, and emits the light of twenty-one suns. The satellite of Procyon is presumably still nearer to extinction than the Sirian attendant. It gives twenty thousand times less light than our Sun, while containing three-fifths of its mass. Recognized by Professor Schaeberle as a thirteenth-magnitude star at Lick in 1896, it shows itself to be unmistakably the "wanted" object by its evident disposition towards conformity with the calculated period of forty years.

A noteworthy example of disturbance by an unseen body is furnished in the system of ζ Cancri. The analysis of this star begun by Tobias Mayer in 1756, was continued in 1781 by Herschel's resolution of the chief member of the Göttingen pair into two very close components. Their orbit lies nearly square to the line of sight, and is described in about sixty years, the third star meanwhile circulating at a rate so much slower that, if continued with approximate uniformity, it would give a period some seven centuries. It does not, however, pursue a steady course. A fly on a revolving wheel imitates its divagations; and the inference is irresistible, and has been ratified by M. Seeliger's exhaustive research, that oscillations included in an eighteen-year cycle are impressed upon motion otherwise elliptical by obscure companionship. In ζ Cancri we are then confronted with two brilliant stars revolving in sixty years, and attended, at about six times their mean distance, by another pair, made up of a bright and a dark member, mutually circulating in eighteen years, while pursuing round the primary pair a leisurely course comprised in an *annus magnus* of, perhaps, seven centuries. In such a system complex perturbations must arise; and their investigation may, in the distant future, disclose unforseen possibilities in celestial mechanics. But their effects are at present unapparent. The condition of the dark star suggests more facile speculations. An attractive force, certainly powerful, and probably comparable to

that of our Sun, resides in it; but large masses keep their heat long, hence we cannot be sure that it has cooled down to a temperature suitable for the maintenance of life, else we might imagine it a huge planet, nourishing crowds of happy beings in its capacious bosom, under skies diversified by the simultaneous, or consecutive, presence of three vivid orbs.

On the night of August 11, 1900, Mr. Aitken, of the Lick Observatory, perceived the components of δ Equulei, one of Otto Struve's double stars, to be no further apart than "the thickness of the micrometer-wire"*—that is, the breadth of a spider-line—whereas their computed distance was of thrice that amount. Professor Hussey, accordingly, revised their elements, and halved their period, which he provisionally fixed at 5.7 years. This, the shortest yet assigned to any similar object, has already been fairly verified, and spectroscopic measures are likely, before long, decisively to attest its correctness.

Here we enter upon ground till lately untrodden, and barely suspected, by audacious prevision, to be capable of exploration. Binary stars, which, by their closeness, defy telescopic powers of separation, and lurk, consequently, forever out of sight, are precisely those most readily accessible to spectroscopic detection, one instrument happily supplying the deficiencies of the other. And traditional astronomy has given splendid proof of its vitality and versatility by the zeal with which it has appropriated, refined, and modified the novel methods unexpectedly placed at its disposal. Investigations of double stars are fundamentally concerned with dynamical problems. Analytical formulæ are employed in them; they move along the consecrated lines of mathematical procedure; they bear the antique stamp. Yet it was just here that the spectroscope most effectively intervened. Among all the improbable developments of recent astronomy there is none stranger or fraught with a deeper significance than that by which acquaintance has been made with "spectroscopic binaries."

It rests upon an easily intelligible principle. Light is a sensation caused by ethereal vibrations striking the retina in swift succession, and color depends upon the rate of their arrival. The rate of their arrival, however, naturally follows the inverse proportion of their length. Red waves being longer than green, fewer of them—since all are propagated with the same velocity—can impinge upon a given surface in the given time; and, similarly, green waves are less frequent than blue and violet. But if the

* *Publications Astr. Society of the Pacific*, No. 75, Vol. CXCVII, No. CCCCIII.

source from which they emanate be in motion towards the eye, they crowd in with augmented rapidity; in other words, the wave-length is shortened and the color changed, red rays tending to become yellow, yellow rays green, and so on. The converse effect is, of course, produced by motion away from the eye, which lengthens the light-waves and correspondingly depresses the color-scale. These alterations are in general minute in amount; but they can be determined with a high degree of exactness by measuring on photographic plates the positions of known dark or bright lines in the displaced spectra. The practical applicability of this beautiful principle to ascertain the radial movements of the stars was exemplified by Sir William Huggins in 1868, since when its importance and subtle power have become continually more manifest.

Spectroscopic binaries are, then, revealed by the periodical motion-shifts of their spectral lines. Only radial or end-on speed can thus be rendered apparent, while velocity directed across the line of sight is alone perceptible to the eye. But either component serves the purposes of the astronomer equally well. The number and variety of the systems brought to his cognizance by the recondite means just described are most surprising. According to Professor Campbell's moderate estimate, one star in five or six is intimately associated with a body of comparable mass, though often non-luminous. Some threescore pairs of the kind have, in fact, been registered in thirteen years, without deliberate search being made for them. They have come to hand as bonuses on dividends accruing from other celestial investments. The first star spectroscopically divided was Mizar, the middle "Horse" of the Plough, designated by Bayer ζ Ursæ Majoris. Its spectrum, photographed at Harvard College in 1889, came out intermittently double, the dark lines alternately opening out into pairs, and closing up into singleness. The light was accordingly judged to emanate from two oppositely moving sources; and the period of this unseen double star has been fixed by Dr. Vogel at twenty days thirty-six minutes.* Their orbit is markedly eccentric; but since its plane cannot be determined, its real size, and, consequently, the mass of the bodies pursuing it, remains unknown. It is only certain that it cannot be less than four times the mass of the Sun. The parallax attributed to Mizar by Klinkerfues represents a light-journey of seventy-two years, at which distance our Sun would shine thirty-eight times less brilliantly

* Sitzungsberichte Akad. der Wiss. Berlin, 2 Mai, 1901..

than the star actually does. Its Sirian spectrum alone suffices to intimate a lustre vivid beyond the proportion of its mass. Mizar is, besides, a telescopic binary. Detected by Riccioli in 1650, the fourth-magnitude companion is readily visible with a 3-inch glass. Their relative movement is excessively slow; eighteen thousand years will have nearly elapsed, in M. Flammarion's opinion, before it has carried them once round their centre of gravity. These stars are sufficiently far apart to be quite easily photographed, and make a charming effect on the Paris negatives. There is, however, a still more distant member of the system. Alcor, the "Rider" of the "Horse," drifts with it, and renders it a quaternary combination of enormous span and incalculable period. The twinkle of Alcor may be caught with the naked eye. In mediæval times it was counted a feat to see it; and the proverb "Vidit Alcor, at non lunam plenam" survives as an illustration of the subtlety in minutiæ of those blind to the obvious. But within the last thousand years the little star seems to have appreciably brightened.

The next spectroscopic binary recognized was β Aurigæ, Miss Maury noting the signs of the duplicity during her examination of the Harvard plates. In this case two brilliant globes, giving together the light of twenty-eight standard suns, circulate in four days, with a velocity indicating a minimum attractive power equal to that of 4.7 suns. A few months later, Spica, the *lucida* of the Zodiacal Virgin, was announced from Potsdam to revolve, also in four days, round a semi-obscure companion. The movement has, accordingly, the effect, not of doubling the spectral lines but of causing them to swing rhythmically to and fro. To this type belong also the majority of the numerous couples discovered by Professor Campbell, Director of the Lick Observatory. Among them is included the Pole-star, which owns the influence of a non-luminous satellite by describing an orbit with a three-day period. Some outstanding variability of motion suggests, moreover, that the system is triple; but the fact has not yet been definitively ascertained.

To the telescopically triple star κ Pegasi the spectroscope has added a fourth component. One member of Burnham's pair, already mentioned as revolving in 11.4 years, was found by Campbell in 1900 to be intimately united to a dark attendant, round which it wheels in about six days. Another well-watched visual binary—ξ Ursæ Majoris—was similarly resolved into a ternary combination by Mr. Wright, at Lick, in 1900. But these results, though eminently noteworthy, had been thrown by advance into

the shade through M. Bélopolsky's addition, in 1896, of a third member to the stately system of Castor. A fourth member it might, indeed, be fairly called, since a small, comparatively remote star keeps pace—as so often happens—with the lustrous pair. These, roughly measured by Bradley in 1719, continue, nevertheless, to defy computation. The data at hand are, for the present, insufficient to warrant even an approximate estimate of their period. All that can safely be said is that it is likely to be comprised between five hundred and a thousand years. This dilatoriness of movement in the wide, visible orbit contrasts singularly with the prompt circulation, on its own account, of the minor component. Once in three days it travels round an obscure satellite, the iron-lines in its spectrum testifying to a considerable alternating velocity of approach and recession. Moreover, some slight progressive inequalities in the mode of its alteration were interpreted by M. Bélopolsky as effects of perturbation. The major axis, in fact, of the ellipse in which the bright and dark pair circulates pivots round in such a manner that the place of periastron 'boxes the compass' in a period of four and a third years. The disturbance is believed to be occasioned by the flattened shapes of the connected bodies; and this again argues their quick axial rotation. Thus, the system of Castor offers in itself a field for profound and stimulating enquiries.

But perhaps the most critical discovery yet made in this department is that of the duplicity of Capella. The premier star of the northern hemisphere was, by Professor Campbell and Mr. Newall, independently identified in 1899 as a spectroscopic binary, composed of two brilliant orbs, circuiting each other with a relative velocity of thirty-six miles a second, in a period of 104 days. They are spectrally dissimilar. The primary gives light of precisely the solar quality; its companion is a star of the intermediate variety exemplified by Procyon. Either of them would vastly outshine our Sun. Capella is the only spectroscopic binary with a well-determined parallax. It corresponds to a light-journey of forty years. We see the star where and as it was four years before the battle of Sadowa. Its luminous output is then measurable, and proves to be no less than 102 times that of the Sun. The solar component, moreover, contributes at least twice as heavily to this total as its less advanced attendant. It is a globe of about seventy times the Sun's light-power, and might reasonably be supposed to possess a radiating surface of seventy times the solar photospheric area. This being so, its volume should be 586 times that of our Sun; and, provided there

were no difference in mean density, 586 times the Sun's attractive force should reside in this prodigious body. Now, there is some reason to believe that Capella has actually been *seen* as a pair at Greenwich. Not distinctly separated, it is true, but, at the proper intervals given by the spectroscopic data, as an 'elongated' disc. This is not impossible, and would afford striking testimony to the qualities of the twenty-eight inch refractor lately built for the Royal Observatory by Sir Howard Grubb; but at Lick the star has always, up to this, seemed perfectly round. An orbit has, however, been calculated from the Greenwich measures, imperfect though they necessarily are; and it implies that the joint mass of the couple is seventeen times that of the Sun. The discrepancy with the known strength of their light-emission is startling; nor is it likely to be ever completely reconciled. Researches into the evolutionary history of the stars tend continually to enforce the conviction that the giant suns of space are, in general, comparatively tenuous in composition—that their gravitating power bears a small proportion to their shining faculty. Investigations of the system of Capella will have an important bearing on this fundamental question.

We now come to binaries which are variables as well. They are variable, moreover, in a special manner. Usually constant in light, they are subject to brief, regular accesses of obscurity. They are, in fact, mutually eclipsing pairs. Their existence is, so to speak, inevitable. Among a number of close double stars there must be a certain proportion revolving in planes passing nearly through the Earth, and hence occulting one another when they come into conjunction. The model 'eclipse-star' is Algol, in the Head of Medusa. The true explanation of its changes was suggested in 1783 by John Goodricke, a lad of eighteen, one of those 'whom the gods love.' Upwards of a century later, the theory, having been worked out in detail by Pickering, was spectroscopically verified by Vogel. He found that, previously to each minimum, the star had a large velocity of recession, and, subsequently to each minimum, an equal velocity of approach.* The eclipses then occur at the furthest part of the orbit, when the radiant primary passes behind a dark, bulky satellite. They last about twelve hours, and recur once in two days twenty-one hours. Their duration serves to measure the size both of the occulted and of the occulting body, giving for Algol itself a diame-

* Deducting, that is to say, the uniform rate of 2.3 miles a second, at which the entire system advances in our direction.

ter of 1,000,000 miles, for the companion one of 830,000. Yet both together probably contain no more than two-thirds the solar quantity of matter. There is little doubt, however, that the bright star far surpasses the Sun in areal lustre. And this heightens the anomaly of its association with an extinct globe. Extinct, or still-born; for the companion of Algol may never have possessed any true cosmic vitality. The frequency of such examples is most remarkable.

Another besides Algol is met with in δ Libræ, the similar light-changes of which were similarly accounted for by Mr. W. S. Adams's spectroscopic demonstration, in 1902, of the star's binary character.* A third eclipsing star—λ Tauri—certified to be such by M. Bélopolsky in 1897, belongs to a different category. The companion is, in this case, to some extent luminous; and the corresponding slight secondary eclipse was noted by M. Plassmann, of Münster, twelve years ago. A peculiar variety of the Algol class was first signalised in U Cephei, a circumpolar star which drops rapidly to one-seventh its normal brightness once in two and a half days, the totality, as it may be termed, lasting two hours. Professor Pickering supposes that, during those two hours of "stationary minimum," the body seen at maximum is entirely concealed by a satellite of greatly superior dimensions, though far inferior luminosity. The orbital movement of this extraordinary pair appears to be subject to marked perturbations, the unravelling of which should materially increase knowledge. Analogous conditions evidently prevail in the system of W Delphini. The variability of this object was detected by Miss Wells, of Harvard College, through the absence from one photographic plate, examined by her, of a tiny star-dot imprinted upon seventy-one others of the same region. This was in 1895, and the eclipse so strangely attested had taken place September 16, 1891, when the star, being below the twelfth magnitude, was chemically inefficient.

About twenty-six Algol-stars have already been registered, and their disclosure proceeds apace. They present phenomena of the utmost variety. Every phase and gradation of eclipse operates in producing the endlessly modified obscurations we witness. Some obviously arise from the alternate transits of two equally bright globes. Of this sort are the minima of Y Cygni. They are duplicated in every period of revolution, and recur once in thirty-six hours, when the normal light of the star is halved.

* *Astrophysical Journal*, vol. xv. p. 214.

The components thus appear to be twin globes, totally eclipsing one another as they gyrate level with the line of sight. Their orbit itself has been ascertained by M. Duner, from photometrical evidence, to revolve in forty-one years. For the changing relations of its elliptic form to the line of conjunction alter sensibly and regularly the intervals between successive eclipses. This same kind of disturbance has become manifest, as our readers will not need to be reminded, through spectroscopic measures in the system of Castor, and is doubtless, in both cases, due to an identical cause.

The chances of eclipse diminish progressively as the periodic time of the revolving bodies increases; and the chances of detection likewise. Firstly, because a smaller angle of inclination suffices for the escape of mutual projection in a wide, than in a narrow orbit; secondly, because eclipses, even should they occur, must be relatively infrequent. The stars could then be caught at minimum only by a happy accident of observation. And we find, accordingly, that Algol-variables are usually very rapid couples, some of them finishing a circuit in less than a day. The slowest of our acquaintance, until quite recently, was S Cancri, with its period of nine and a half days. But in April, 1902, Mrs. Fleming, who ably superintends the women's department of photographic measurement at Harvard College, discovered a star in Cygnus, the phases of which are recurrent in thirty-one days, and need two for their completion. A stationary minimum lasting twelve hours seems to imply a total eclipse by a dim, distended body, giving no more than one-sixteenth the light of the comparatively small star with which it forms an ill-assorted couple.

Three variable stars, namely, δ Cephei, η Aquilæ, and ζ Geminorum, have been found to revolve round obscure companions in the precise period of their light-change, yet without undergoing eclipse. This negative inference is based upon spectroscopic evidence showing that they are far from conjunction at the epochs of minimum. Their variability, accordingly, offers a still unsolved problem. The fluctuations, nevertheless, of another species of "short-period variable," are plausibly referred to a purely geometrical cause. They continue, indeed, without interruption, and must hence be significant of the continuous though alternating superpositions of two bright spheres or spheroids. Yet the required conditions, which have been developed by several investigators, are not wholly inadmissible; and if they do not square with preconceived notions, the notions, we suppose, must give

way to the facts. A star in the Poop of Argo belongs to this peculiar class. Mr. A. W. Roberts, of Lovedale, Cape Colony, who has cultivated, with signal success, the field of stellar variability, long neglected in the southern hemisphere, defined precisely, in 1900, after several preliminary attempts, the law of light-change for V Puppis.* That a binary combination was really in question had been already proved by spectrographic determinations at Harvard College; and Mr. Roberts showed that the components match in size, although not in brightness, and hence produce, by their mutual transits, eclipses of unequal depth, each pair being comprised in the orbital period of thirty-five hours. And since they proceed continuously, one merging into the next, it is clear that the stars revolve in contact. They must also be considerably distorted in shape by their unsymmetrically acting pull upon one another, and this again cannot but sensibly modify the course of the phases. Theoretically, in fact, it ought to be possible to fix the extent of deviation from sphericity in the occulting globes from measures of their increasing and decreasing light. But in practice this possibility could not be realized, "the conditions of the problem," as Mr. Roberts says,† "being too complex, the nature of the forces to be considered too indefinite, and the data at our disposal too meagre" to admit of a satisfactory conclusion being arrived at.

The stars of V Puppis are extremely tenuous bodies. If truly contiguous, they cannot, Mr. Roberts finds, be of more than one-fiftieth the Sun's density, or one thirty-eighth that of water. This may seem difficult of admission, yet the well-ascertained high degree of rarity in other sidereal masses bids us hesitate to pronounce it incredible, especially since data procured with the spectroscope will, when fully discussed, serve decisively to test the matter.

V Puppis is not an unique specimen of a "dumb-bell" system. The ingenious calculations of Professor G. W. Myers‡ warrant the belief that another is met with in the famous variable β Lyræ; and the light-changes of U Pegasi and R^2 Centauri are of a strictly analogous character. Such combinations inspire extraordinary interest. They place before us double stars in process of being made, and instruct us, in the most authentic manner, as to the nature of the process. Their existence might indeed be described as a corollary to certain propositions laid down by Dr.

* *Astron. Journal*, No. 477.

† *Astrophysical Journal*, vol. xiii, p. 188. ‡ *Ibid*, vol. vii, p. 1.

T. J. J. See in a thesis first printed in 1892 as a diploma performance for the degree of Doctor of Philosophy in the University of Berlin, and quoted, in the more extended form afterwards given to it, among the headings to this article. It quickly made its mark, and has strongly and permanently influenced the thoughts of cosmogonists.

Dr. See was forcibly impressed with two points of contrast between the planetary scheme and the binary systems studied by him. These, he noticed, in the first place, move in orbits of markedly elongated shapes. He estimated "the average eccentricity among double stars at about twelve times that found in our own system." Further, the approximate equality in mass of conjoined stars compared so strangely with the enormous disparity, in this respect, between the Sun and his planets that he proceeded to enquire whether these characteristics might not be connected as cause and effect. An affirmative answer was recommended by a full development of the theoretical consequences of tidal friction.

These were first adequately discussed in Professor Darwin's memoir on the origin of the Moon, presented to the Royal Society, December 18, 1879. The condition of our satellite, however, exemplifies them but feebly in comparison with the pronounced form which they must take in a multitude of stellar systems. For they gain importance with the approach to equality of the bodies acted upon. Solar tidal friction, accordingly, has not, it would appear, sensibly modified the orbital movement of any of the solar dependents. It has, indeed, checked the rotation of some of them through the operation of sun-raised tides; but the counter-effects of tides raised by planets on the Sun are too small to be of any account. But the Earth and Moon are not so vastly disproportioned in mass as the Sun and the largest of his planets; and here both orbital and axial motion betray the influence of tidal friction, although by no means to the same extent as where co-ordinate globes are concerned.

"Tides," Dr. See writes, "are cosmic phenomena as universal as gravitation itself; and since tidal friction will operate in every system of fluid bodies which is endowed with a relative motion of its parts, we see that the general agency of bodily tides gives rise to most important secular changes in the figures and motions of the heavenly bodies. The tidal alterations of figure, which modify the attraction on neighboring bodies, will become especially marked in the case of double stars and double nebulæ, where two large fluid masses in comparative proximity are subjected to their mutual gravitation; and hence, if the bodies of such a system be rotating as well as revolving, the secular working of tidal friction becomes an agency of great, and, indeed, of paramount importance. . . .

It seems exceedingly probable that the great eccentricities now observed among double stars have arisen from the action of tidal friction during immense ages; that the elongation of the real orbits, so unmistakably indicated by the apparent ellipses described by the stars, is the visible trace of a physical cause which has been working for millions of years. It appears that the orbits were originally nearly circular, and that under the working of the tides in the bodies of the stars they have been gradually expanded and rendered more and more eccentric."

The lag of tide-waves on viscous spheroids is the circumstance essential to the process in question. Their displacement forward, consequent upon rapid rotation, enables them to pull the tide-raising body along a slowly widening path; and since this pull varies inversely as the seventh power of the distance, the slightest initial deviation from circularity in the orbit of the affected body sets up a progressive inequality in the strength of its action. Moreover, the condition for starting it is sure to be present, orbits never being geometrically perfect circles. Unsymmetrical expansion hence ensues, and increased eccentricity.

Now if, during unnumbered ages, tidal friction has effectively tended to push double stars apart, there must have been a time when they were quite close together—when they circulated quickly along very slightly oval tracks, in periods of a few days or hours. They would then have been spectroscopic binaries. Further, the mathematical investigations of Jacobi, Poincare, and Darwin countenance the view that such pairs originated through the fission of a primitive spheroid, or "apioid," under the stress of its accelerated rotation, and this gradually and tranquilly, duplicity developing almost insensibly out of singleness. Stars like V Puppis are thus, we are led to believe, in the stage antecedent to complete separation. It is hard to say whether, at the present moment, they are double or single. They still cling together, but merely by their common possession of a shallow photospheric layer, destined probably in a future that may be called immediate, by cosmical time-reckoning, to break up, and leave the stars distinct, though intimately connected bodies. And the double system at last formed will begin at once to undergo the all but endless processes of tidal evolution.

Here then, so far as human insight has yet penetrated, we have the history of the majestic systems with which the heavens are profusely strewn. They are, in their main outlines, the products of tidal friction. Through its agency, spectroscopic developed into telescopic binaries. Even within the precincts of the solar domain, Professor Darwin's insistence upon its effects has profoundly altered the aspect of cosmogony; and Dr. See's further research leaves little doubt that they have been incomparably

more influential upon the relations of coupled stars than upon those of the Sun and planets. The early stages of creation are contemplated by us from a point of view unattainable by Laplace or Herschel. We not only recognize potencies totally unknown to them, but we learn from their ignorance to estimate our own. The glimpse we have gained of complex powers and influences strange to our predecessors warns us to be prepared for the subversion of our theories by the subtle intervention of others still undisclosed and unimaginable.

The wide prevalence of a conjugate arrangement among the suns of space is one of the most remarkable facts in nature. That it has an express purpose we cannot hesitate to admit, although its drift defy our faculties of conjecture. We instinctively look to organic life as the one end of all the contrivances displayed in celestial architecture; but double stars can scarcely, according to our ideas, provide ideal abodes for animated beings. Their trains of planets, if any are attached to them, would be exposed to extreme vicissitudes of climate, and vehement perturbations of movement. The adventures of comets falling under the temporary sway of Jupiter exemplify the possible lot of dependent bodies in a duplex system. Their elliptic orbits might, at a given moment, be transformed into hyperbolas, when the inhabited worlds traversing them would, irresistibly and irrevocably, be driven forth into outer darkness, to wander homeless through the unending solitudes of space.

The truth is, as Dr. See has well pointed out, that we do not know, and have no means of knowing, whether or not the solar family is solitary in the universe-

"If such inconsiderable companions as our Sun possesses," he writes,* "attend the fixed stars, they would neither be visible, nor could they be discovered by any perturbations which they might produce. It is, therefore, impossible to determine whether the stellar systems include such bodies as the planets, and we are thus unaware of the existence of any other system like our own. On the other hand, the heavens present to our consideration an indefinite number of *double systems*, each of which in divided into comparable masses. These double systems stand in direct contrast to the planetary system, where the central body has 746 times the mass of all the other bodies combined. In binary stars, the mass-distribution is evidently *double*, while in the solar system it is essentially *single*. Whether observation," he continues, "will ever disclose any other of such complexity, regularity, and harmony, as our own is an interesting question for the future of astronomy. It is certain that the number of double stars will be augmented in proportion to the diligence of observers and the improvement of our telescopes; and we may reasonably expect a sensible increase in the number of triple and quadruple stars, and of stars attended by dark bodies."

* Evolution of the Stellar Systems, p. 257.

In some of these we might, if speculatively inclined, be tempted to locate astral populations. Nothing, at least, prohibits our so doing. The obscure companions of Algol-stars are, indeed, scarcely condensed enough for that purpose; they have not attained planetary consistence; but members of telescopic systems which gravitate without radiating, such as the invisible component of ζ Cancri, might reasonably, apart from the doubt already expressed regarding their superficial temperature, be deemed habitable in the familiar sense of that vague term. We cannot know, we are helpless to conceive, what resources of infinite wisdom might, in combinations of the sort, be brought into play. But we are entitled to infer the moral from the proved physical oneness of the universe. We may rest assured that our intuitions of truth and beauty, far from being peculiar to humanity, are shared, perhaps in a transcendent degree, by sidereal beings who know as we know, if more surely and clearly, and worship what we worship, though, we may hope, with a fuller apprehension of the Eternal Majesty.

EARLY HISTORY OF ASTRONOMY AT AMHERST COLLEGE.

PROFESSOR DAVID TODD.*

For Popular Astronomy.

Astronomy at Amherst is first mentioned in the Catalogue for 1825. It was taught in the third term of the Junior year, from Enfield's *Philosophy*, an English text used down to 1833, when Herschel's treatise was adopted.

Enfield's treatment was mainly geometrical; and I have recently examined his worthy work to see how the astronomy of that day compared with our own. Among many curious statements I find the teaching that the Sun is inhabited—following no doubt the expressed belief of the elder Herschel. "Comets are opaque and solid bodies." There is no mention of the Sun's corona, nor of meteors; and the chapter on the Sun is but a little over one page long. Enfield's *Philosophy* was revised by President Samuel Webber† of Harvard College, and it must have proved well adapted to counteract "that effeminacy and frivolity which distinguish the present age."

From 1825 to 1829 astronomy was taught by the Rev. Jacob

* Address by Professor David Todd at the breaking of ground for the new Observatory on Wilder Hill, May 2d, 1903.

† V. Mrs. Todd's *Total Eclipses of the Sun*, p. 114.

Abbott, father of Dr. Lyman Abbott. In the college catalogues of those early days are many items of quaint interest. Commencement came on the fourth Wednesday of August; to offset which, there was a vacation of six weeks onward from the fourth Wednesday of December. Term bills, including tuition, room rent, etc., were $10 to $11 per term. Board $1.25 per week; hard wood, specified of good quality, $1.75 to $2 per cord.

In 1829 Tutor Snell was appointed professor of mathematics and natural philosophy, and he taught astronomy for the next twenty years. Professor Olmstead of Yale wrote an excellent text-book on astronomy, which was adopted by Professor Snell in 1839; and the work was revised by this unique teacher and able author in the early sixties, when it was widely used throughout the country.

Professor Hitchcock, the eminent geologist, became the third president of Amherst in 1845. The life of the college was at a very low ebb, but the new administration imparted immediate vigor, and the college speedily advanced to the foremost rank.

On Hitchcock's accession to the Presidency, the observatories of the country might have been counted on the fingers of a single hand. But this great scientist's interest in astronomy, coupled with the advent of the great comet of 1843 and the discovery of Neptune in 1846, must be regarded as determinant in the building of Amherst's first Observatory (the present one); and it was rushed forward to completion in the summer of 1847. The catalogue for 1847-8 contains a fine frontispiece of the college, with the present "octagon," or Cabinet and Observatory in the middle ground. Charles B. Adams was appointed adjunct professor of astronomy, and curator of the Cabinet; and the composite type of building was doubtless decided upon, to suit the exigency of the divided, and now seemingly incongruous, arms of his chair. From 1849 to 1853, Adams was professor of astronomy and zoology, and the collections of our cabinets are rich with the fruit of his harvests in Jamaica and elsewhere.

The marble tablet in the old Octagon commemorates the donors: the Hon. Abbott Lawrence of Boston gave $1,000, the largest sum of all, so that the eastern portion of the building was named for him, Lawrence Observatory.

The Hon. Josiah B. Woods of Enfield collected the funds in the main, about $9,000 "from the liberality of more than forty gentlemen in the Commonwealth." So the Cabinet was named for him "The Woods Cabinet."

The Observatory was dedicated on the 28th of June, 1848, the

Hon. W. B. Calhoun making the principal address, and the eminent Professor Silliman, the elder, of Yale, also an inspiriting speech.* In his introductory remarks, President Hitchcock characteristically said, "We have no telescope with which to grace the pedestal of the tower; but we should be very faithless and ungrateful to doubt that the same Providence which has done so much for us the past year, will send us a fitting telescope, if it be best for us to have one; and send it too just at the right time."

Still, tower and dome stood for five years without any telescope; but in 1852-3 the present equatorial with a glass of 7¼ inches aperture and 9 feet focus was constructed and mounted in the dome by Alvan Clark & Sons. This was the first equatorial completely built by this firm, and it was presented to the college by the Hon. Rufus Bullock, of Royalston. Two new double stars were discovered with it by the makers; and the elder Clark, perhaps the most famous builder of telescopes the world has ever seen, received the degree of M. A. from the college at commencement in 1854. Harvard gave him the same degree twenty years later.

The old transit instrument and clock were mounted where they now are, in the eastern wing of the Observatory. These instruments, Brejuet clock and Gambey repeating circle, were obtained in Paris by Professor Hovey, as early as 1831. So that Amherst seems to have been, excepting Yale, the first college in the country to begin providing an equipment of astronomical instruments. But this transit like Burnham's famous micrometer, may be said to embody more defects of construction than any other transit ever built in any age of the world; and after a quarter century of use, I frankly say that I have never been able to determine all the errors to which it is subject. It was the work of Gambey of Paris, and its defects are those of design, not workmanship.

It is interesting to note that in the year after Amherst bought this transit, Congress took the trouble to legislate expressly that the government should neither construct nor maintain an astronomical Observatory.

Mr. W. C. Esty was appointed instructor in mathematics in 1862, and Walker Professor, his present billet, in 1865. He taught astronomy for sixteen years, until the appointment of the present incumbent in 1881, who then became Director of the Ob-

* A description of the Observatory, illustrated by a wood engraving, may be found at page 263 of Loomis's *Recent Progress of Astronomy* (1856); and there is brief mention of it in André et Angot, *L'Astronomie Pratique*, iii. 114.

servatory. Mr. T. D. Biscoe, now professor in Marietta College, was appointed instructor in mathematics in 1865, and spent much time in the Observatory, building several accessory instruments. Professor Esty amplified the courses in astronomy, adding Observatory work, and during his incumbency all the courses were made elective.

In 1881, President Seeley invited the writer to the chair of astronomy, with the expectation of building a new Observatory. In 1893 the sum of $50,000 was promised for this purpose; but owing to the unsettled financial conditions of that and subsequent years, this offer never was made good. Many sites were considered, but nothing decisive was done until 1897, when the bequest of the late Mr. Charles T. Wilder enabled the trustees to purchase the residence, and the land adjoining that where we now stand. In 1899, the first preliminary plans for the new Observatory were drawn and a fine perspective executed by Messrs. York & Sawyer, architects of New York.

In October, 1900, the promise of $25,000 was made to the writer, for the construction and equipment of a new Observatory, conditional upon his raising a like sum from other sources. This first made the project for rehabilitation of the department seem likely to be executed. For the completion of this fund, the department and the college are indebted to alumni and other friends of this institution, whose names will be duly commemorated elsewhere. At commencement, 1901, the new Observatory was assured.

The title to the land on which the new building is actually to stand was acquired by gift of Mr. D. Willis James in January, 1903. This tract of about two acres makes a complete reservation of continuous college property (with the grove and both athletic fields), nearly forty acres in extent; and it may be considered as sufficient for future protection of Observatory interests, especially as the horizon is open in every direction. The elevation above sea level is something in excess of 300 feet.

Tentative plans were drawn in the winter of 1901-2 by Messrs. McKim, Mead & White of New York, and the Trustees appointed Mr. George A. Plimpton, Mr. D. Willis James, and Mr. G. Henry Whitcomb a Committee on the Observatory. The completed plans contemplate a structure about 150 feet long, east and west, and surmounted by three domes, the central one of which is thirty-three feet in diameter.* This will house an equatorial tele-

* *Popular Astronomy*, January, 1903.

scope with a glass eighteen inches in diameter, and twenty-one feet long. The Alvan Clark & Sons Corporation of Cambridge are already well advanced with the construction of this telescope, and have contracted to complete it in time for commencement of 1904.

In consequence of the present high cost of building operations, only the large dome and the eastern one of the two lesser domes (with the intervening room for transit instruments) will be built the present season.

Omitting numerous lesser gifts, also neglecting the sum of about $50,000 expended on various astronomical expeditions, the permanent funds and equipment of the department of astronomy and navigation acquired during the writer's incumbency, are as follows:

Sidney Dillon Foundation, 1888	$ 25,000
Eclipse instruments, Expeditions of 1889 & 1896	6,500
Observatory House and Wilder Hill, 1897	15,000
Observatory Construction Fund, 1900-1901	50,000
Addition to site by D. Willis James, Esq	3,500
	$100,000

Present at the initial ceremony of breaking ground, were the following, in addition to the President and Faculty of the College:

Dr. Woolley, President of Mount Holyoke College; Professor Van Vleck of Wesleyan University; Miss Byrd, Director of the Observatory of Smith College; Miss Young, Professor of Astronomy in Mount Holyoke College; Mr. Carl Lundin of Alvan Clark & Sons, with many others.

Precedent to Professor Todd's address there was reading of selections from the Scriptures by the Rev. Dr. George Harris, President of the College; and immediately following it, Mr. George A. Plimpton, Chairman of the Observatory Committee of the Trustees, pronounced the following old Latin blessing (1490): *Benedicite, Dominus, nos et ea quae sumus facturi; benedicat dextera Christi. In nomine Patris et Filii et Spiritus Sancti, Amen.*

He then turned the first sod, after which the prayer offered by the Rev. Dr. Henry Preserved Smith concluded the exercises.

Subsequent to the ceremony of breaking ground on the hill, Mr. George W. Cable of Northampton planted a maple at the astronomer's dwelling, another welcome addition to the trees already christened by Mrs. Julia Ward Howe, Mrs. Alice Freeman Palmer, Dr. Edward Everett Hale, Col. Thomas Wentworth Higginson, and other guests during the past five years at Observatory House.

RELATION OF THE MOON TO THE WEATHER.

WILLIAM H. PICKERING.

FOR POPULAR ASTRONOMY.

To most of us who have been brought up to consider that it is rank heresy to suggest that the Moon has any influence on the weather, it is a little startling to look up the amount and quality of the data that have been collected upon this subject, especially in Germany. The point which seems to have been particularly investigated is the relation of the phases of the Moon to thunder-storms.

In the following table the first two columns give the name of the city or country where the observations were made, and the name of the authority for the observations. The next two columns give the first and last year included in the count. The fifth column gives the number of years over which the observations extend. The next four columns give the percentage of thunder-storms that occurred in the seven or eight days nearest each phase of the Moon. Of these four columns the sum of the first two is given in the next column, and the sum of the other two in the last.

THE MOON'S PHASES AND THUNDER-STORMS.

Station	Authority.	From	To	Years	New	First	Full	Last	New First	Full Last
Kremsmünster	Wagner*	'02	'87	86	26	28	21	25	54	46
Aix la Chapel	Polis*	33	92	60	27	27	22	24	54	46
Batavia, Java	Van d. Stok*	87	95	9	27	25	24	24	52	48
Gotha	Lendicke†	67	75	9	35	38	12	15	73	27
Germany	Köppen†	79	83	5	26	30	20	24	56	44
Glatz County	Richter†	77	84	8	33	29	18	20	62	38
N. America	Hazen†	—	84	1	30	27	24	19	57	43
Prague	Gruss†	40	59	20	27	24	27	22	51	49
"	"	60	79	20	26	27	25	22	53	47
Göttingen	Meyer†	57	80	24	27	27	22	24	54	46
Greenwich	MacDowell‡	89	01	13	31	23	22	24	54	46
Madrid	Ventatasta	82	01	20	29	23	22	26	52	48
Providence, R. I.	Seagrave¶	96	01	6	31	18	27	24	49	51

* *Lehrbuch der Meteorologie*, Hann p. 662.

† *Meteorologische Zeitschrift*, 1888, XXIII, 115.

‡ *Nature*, 1902, LXV, 367.

¶ *Popular Astronomy*, 1902, X, 332.

A comparison of the last two columns shows that with one exception the number of storms occurring near the first two phases of the Moon is always greater than the number occurring near the last two. An examination of the four preceding columns shows that only in four cases is the largest number in either of the last two phases as large as the smallest number in either of the first two phases.

At Gotha and Glatz County, apparently, two storms occur during the first two phases, to one that occurs during the two last. It is interesting to note though these two stations are less than 300 miles apart, that the observations are made in two different series of years, thus giving added force to the results. Hazen's results which also show a marked, although less, difference in the last two columns, while extending through only one year, should have considerable weight, as they include nearly 12,000 storm observations. Counting however only those places where records have been kept for twenty or more years, we find that twelve per cent more storms occur during the first two phases than during the last two.

The number of observations here collected seems to be large enough to enable us to draw definite conclusions, without fear that further records will revise or neutralize them. From these observations we conclude that there really is a greater number of thunder-storms during the first half of the lunar month than during the last half, also that the liability to storms is greatest between new moon and the first quarter, and least between full moon and last quarter. Also we may add that while theoretically very interesting, the difference is not large enough to be of any practical consequence. Thus it would seem that besides the tides and certain magnetic disturbances, there is a third influence that we must in future attribute to the Moon.

HARVARD OBSERVATORY,
May 18, 1903.

PHOTOMETRIC MAGNITUDES OF COMPARISON STARS FOR NOVA GEMINORUM.

J. A. PARKHURST.

FOR POPULAR ASTRONOMY.

Now that the Nova is too near the Sun for observation, it seems a proper time to publish provisional magnitudes for some of the comparison stars, in order that the numerous observations, visual and photometric, may be reduced on the same scale. The following table is offered as a contribution towards this end. The observations were made with the "equalizing wedge photometer" described in *Astrophysical Journal*, XIII, 249, used with telescopes of 6, 12 and 40 inches aperture.

BASIS FOR THE MAGNITUDES.

The stars *g*, *h* and *l*, of the table, were measured both at Har-

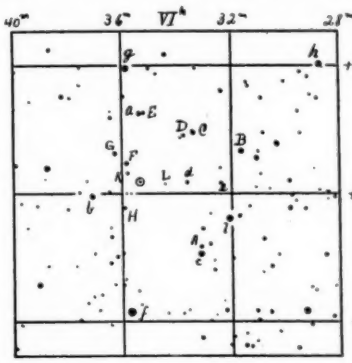
vard and Potsdam with the following results:

Star	H. C. O. Vol. 45	P. D. M.
g	7.13	7.50
h	7.23	7.60
l	7.36	7.22
Mean	7.24	7.44

Although the relative magnitudes in the two catalogues are not in the same order, the difference between the means is in the right direction and fairly accordant in amount, with the systematic difference between the catalogues*; these stars are therefore as well adapted for standards as any in the vicinity.

Measurement of Comparison Stars.

With the stars *g*, *h* and *l* as standards, *b*, *c*, *d* and *e* were measured with the 6-inch; and continuing the process, *m*, *o*, *p*, and *q* were measured with the 12-inch, and *r*, *s*, *t* and *u* with the 40-inch. Although the last four stars are not of immediate use in measuring the Nova, they are of considerable value in fixing the photographic magnitude of the image found on the plate taken here on Feb. 21, 1903 and described in Bulletin No. 19 of Yerkes Observatory. (This plate is reproduced in the June number of the *Astrophysical Journal*). This image seems to occupy the exact place of the Nova. It is perhaps half a magnitude brighter than the star *t*, and may therefore be taken as approximately 14.5 magnitude. It will be noticed that the retouched image on Mr. Dugan's plate in Popular Astronomy for May 1903, page 260, is too far south for the Nova, so that it will be necessary to refer to the original plate or an untouched copy to decide on the presence or absence of the Nova image on that date. It may be added that my plate shows stars two magnitudes fainter than the print of Mr. Dugan's plate, but it must be remembered that a reproduction of a print will never show all that is on the original negative.



Nova Geminorum Scale of the DM.

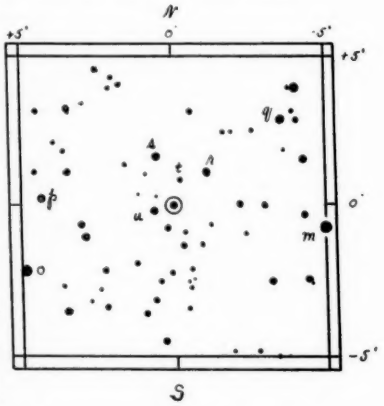
* Pub. Potsdam Observatory, XIII, 459.

PROVISIONAL MAGNITUDES OF COMPARISON STARS FOR NOVA GEMINORUM.

Star	DM. No.	DM. Mag.	Photometric Magnitude.	No. of measures.	Star	DM. No.	DM. Mag.	Photometric Magnitude.	No of measures.
	°					°			
g	+30 1318	7.0	7.33		*a*	+30 1314	8.2	8.19	3
h	31 1363	7.0	7.34		*A*	29 1319	8.6	8.63	3
l	29 1307	7.2	7.05		*B*	30 1300	8.0	8.25	3
					C	30 1305	8.2	8.38	3
b	29 1342	8.2	7.76	3	*D*	30 1307	8.8	9.02	3
c	29 1320	7.8	7.44	5	*E*	30 1313	8.6	9.44	3
d	30 1306	8.6	9.02	3	*F*	30 1316	9.0	9.62	3
e	30 1302	9.2	9.27	3	*G*	30 1320	8.9	9.20	3
					H	29 1328	9.2	9.73	2
m			10.56	7	*L*	30 1309	9.4	9.97	2
o			11.19	3	*K*			10.16	2
p			11.99	2					
q			12.03	2					
r			13.27	4					
s			13.11	4					
t			14.84	1					
u			13.29	2					

TABULAR MAGNITUDES OF THE COMPARISON STARS.

These are given on the basis of the Harvard system. To express on the Potsdam system add 0.20 to the results. These magnitudes may be called "scale 2," being based on more observations and a later revision than the list in the June *Astrophysical Journal.*



NOVA GEMINORUM. LARGER SCALE.

THE CHARTS.

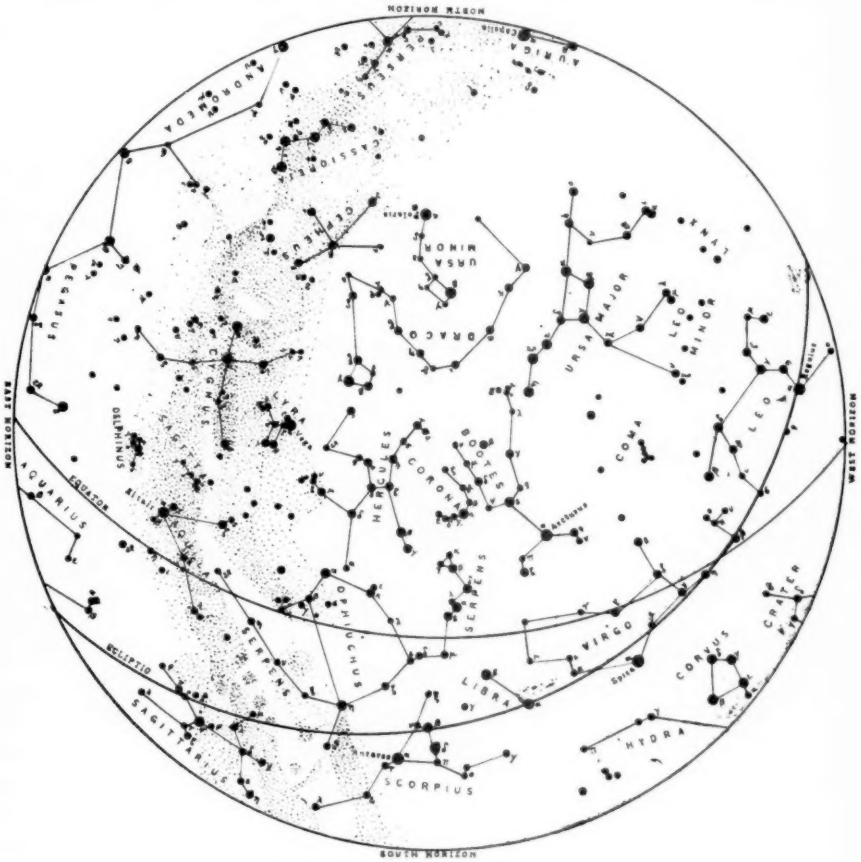
The chart headed "Scale of the DM." is a hand copy of the DM. chart, showing stars to the 9.5 magnitude. That headed "Larger Scale" is a hand copy carefully made from a photograph of the immediate vicinity of the Nova, and shows stars down to the 17th magnitude, no star of that brightness being omitted within 2′ of the Nova. All the comparison stars fainter than 10.2 magnitude will be found on the large scale chart but none of the DM. stars are shown on it.

YERKES OBSERVATORY,
May 19, 1903.

PLANET NOTES FOR JULY AND AUGUST.

H. C. WILSON.

Mercury will be visible as morning star during the first few days of July and will be invisible during the remainder of the two months. The planet will be at superior conjunction on July 26. In coming out from behind the Sun in August



THE CONSTELLATIONS AT 9 P. M. JULY 1, 1903.

Mercury will come into conjunction with Venus on Aug. 28, but the two planets will be about 6° apart in declination and both will be too near the Sun to be readily seen.

Venus will be at greatest elongation east from the Sun, 45° 30′, on the evening of July 9. A number of fairly good views of the gibbous disk of Venus have

been obtained during May with the 16-inch telescope of Goodsell Observatory, but on no occasion have any definite markings been detected on the face of the planet. During August Venus will move rapidly in toward the line joining Earth and Sun. Her greatest brilliancy will be attained about Aug. 12, when the illuminated crescent will cover only one quarter of the apparent diameter of the disk, On July 5 Venus will pass quite close to the star Regulus (α Leonis) so that there will then be a splendid opportunity to compare the brightness of the most brilliant planet with that of a first magnitude star. The magnitude of Regulus is 1.36 according to the Harvard photometric scale.

Mars will be at quadrature, 90° east from the Sun July 6 and so will be visible in the early evening during these months. His course will be southeastward. through Virgo into Libra, passing Spica (α Virginis) on the morning of July 23. In recent views of the planet the disk of Mars has seemed to have more than its usual proportion of the large orange-colored areas, very little of the gray or blue areas being in evidence. The north polar cap has been quite distinct and rather small. The south polar cap is at present turned away from us.

Jupiter is now morning star, seen toward the southeast. In August the planet will rise before 9 o'clock so that it may be observed well at midnight.

Saturn will be at opposition July 30 and so may be seen toward the south near midnight. There are no very bright stars in the vicinity of the planet, so that it is very easily recognized by its brightness as well as by its golden color.

Uranus passes opposition in June and so will be visible in the early evening during July and August. One must know just where to look for this planet with a telescope since it is not visible to the unaided eye, but it is easily recognized by its dull greenish-hued disk, as seen in a telescope of moderate power. It is situated in a region devoid of bright stars about midway between the bright stars of the constellations Scorpio and Sagittarius.

Neptune passes conjunction June 25 and will therefore not be visible during the summer.

The Moon.

Phases.			Rises. (Central Standard Local Time 13m less.)		Sets. Time at Northfield	
			h	m	h	m
July	1-2	First Quarter	12	18 P. M.	12	06 A. M.
	9-10	Full Moon	7	42 "	5	40 "
	17-18	Last Quarter	11	47 "	1	41 P. M.
	24	New Moon	5	06 A. M.	7	42 "
	31	First Quarter	1	21 P. M.	11	47 "
Aug.	7-8	Full Moon	6	55 "	5	27 A. M.
	15-16	Last Quarter	11	00 "	1	39 P. M.
	22	New Moon	5	10 A. M.	6	54 "
	29	First Quarter	1	10 P. M.	11	05 "

Occultations Visible at Washington.

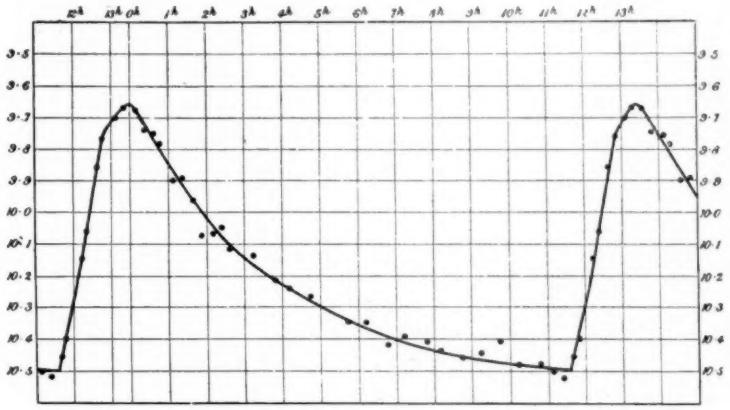
Date. 1903.	Star's Name.	Magnitude.	IMMERSION. Washington M.T. h	m	Angle f'm N pt. °	EMERSION. Washington M. T. h	m	Angle f'm N pt. °	Duration. h	m
July 6	29 Ophiuchi	6.5	8	39	65	10	04	314	1	25
10	B.A.C. 7063	6.2	14	47	120	15	49	198	1	02
16	*e* Piscium	5.7	11	04	101	11	54	220	0	50
Aug. 4	B.A.C. 6287	6.0	9	07	18	9	43	334	0	36
4	B.A.C. 6292	7.5	9	26	78	11	00	270	1	34

Occultations Visible at Washington.—Continued.

Date. 1903.	Star's Name.	Magnitude.	IMMERSION. Washington M.T. h m	IMMERSION. Angle from N pt. °	Washington M. T. h m	Angle from N pt. °	Duration. h m
Aug. 5	ρ^1 Sagittarii	3.9	9 35	85	11 10	254	1 35
7	9 Aquarii	7.0	11 12	123	12 07	196	0 55
10	B.A.C. 8094	5.6	7 28	43	8 19	284	0 51
14	38 Arietis	5.2	16 00	81	17 24	237	1 24
16	75 Tauri	5.3	12 22	149	12 40	187	0 18
19	68 Geminorum	5.0	13 53	140	14 25	225	0 32
31	Y Sagittarii	*var.*	12 34	119	13 23	222	0 49

VARIABLE STARS.

The Variable Star UY Cygni.—In the *Monthly Notices* of the R. A. S. for March 1903 Mr. A. Stanley Williams gives a new determination of the light curve of this variable depending upon 213 observations during the year 1902 and one on Nov. 22, 1900. The curve is found to be almost a facsimile of that of Y



Light Curve of UY Cygni.

Lyræ. Mr. Williams finds the period to be one minute longer than that which has been published heretofore and used in the ephemerides.

Elements of UY Cygni.

Period of Variation = $13^h\ 27^m\ 20^s.85$ = 0.560658 days.
Epoch of T_0 = 1902 Aug. 22 $10^h\ 16^m.6$ Gr. M. T.
= J. D. 2415984.4282
Epoch of maximum = 1902 Aug. 22 $11^h\ 37^m.1$ Gr. M. T.
= J. D. 2415984.4841
Maximum brightness $9^m.66$; minimum $10^m.50$.
Minimum to maximum $1^h\ 53^m$
Maximum to minimum 11 34
Ratio of time of increase to time of decrease 0.16.

Mr. Williams also gives an ephemeris of the computed times of maxima for the remainder of the year, by means of which we have corrected the tables for July and August in this number of Popular Astronomy. The hours given for June in our last number are two hours too early.

Minima of Variable Stars of the Algol Type.

[Greenwich Mean Time beginning with midnight. The hours greater than 12 are those of the afternoon. To obtain Eastern Standard time subtract 5 hours; for Central Standard subtract 6 hours, etc. Alternate minima only are given for these months.]

U Cephei.

	d	h
July	5	16
	10	16
	15	15
	20	15
	25	14
	30	14
Aug.	4	14
	9	13
	14	13
	19	13
	24	12
	29	12

Z Persei

	d	h
July	4	14
	10	16
	16	19
	22	22
	29	1
Aug.	4	3
	10	6
	16	9
	22	11
	28	14

Algol.

	d	h
July	1	23
	7	16
	13	10
	19	4
	24	21
	30	15
Aug.	5	8
	11	2
	16	20
	22	13
	28	7

λ Tauri.

	d	h
July	1	7
	9	5
	17	2
	25	0
Aug.	1	22
	9	20
	17	17
	25	15

RR (R^2) Puppis

	d	h
July	5	23
	18	20
	31	16
Aug.	13	13
	26	10

V Puppis

	d	h
July	1	7
	4	5

V Puppis.

	d	h
July	7	3
	10	0
	12	22
	15	20
	18	18
	21	16
	24	13
	27	11
	30	9
Aug.	2	7
	5	5
	8	3
	11	0
	13	22
	16	20
	19	18
	22	16
	25	13
	28	11
	31	9

S Antliæ.

Period $7^h\ 46^m.8$

	d	h
July	1	14
	3	13
	5	11
	7	10
	9	9
	11	8
	13	6
	15	5
	17	3
	19	2
	21	1
	22	23
	24	22
	26	20
	28	19

S Velorum.

	d	h
July	1	9
	13	6
	25	3
Aug.	5	23
	17	20
	29	17

δ Libræ.

	d	h
July	3	1
	7	16
	12	8
	17	0
	21	16
	26	7
	30	23
Aug.	4	15

δ Librae.

	d	h
Aug.	9	6
	13	22
	18	14
	23	6
	27	21

U Coronæ.

	d	h
July	6	23
	13	21
	20	19
	27	17
Aug.	3	14
	10	12
	17	10
	24	7
	31	5

R Aræ.

	d	h
July	8	16
	17	12
	26	9
Aug.	4	5
	13	2
	21	22
	30	18

U Ophiuchi.

	d	h
July	1	23
	3	15
	5	8
	7	0
	8	16
	10	8
	12	1
	13	17
	15	9
	17	1
	18	18
	20	10
	22	2
	23	18
	25	11
	27	3
	28	19
	30	11
Aug.	1	4
	2	20
	4	12
	6	4
	7	21
	9	13
	11	5
	12	21
	14	14
	16	6
	17	22
	19	14

U Ophiuchi.

	d	h
Aug.	21	7
	22	23
	24	15
	26	7
	28	0
	29	16
	31	8

Z Herculis.

	d	h
July	5	1
	9	1
	13	0
	17	0
	21	0
	25	0
	29	0
Aug.	2	0
	5	23
	9	23
	13	23
	17	23
	21	23
	25	23
	29	22

RS Sagittarii.

	d	h
July	5	12
	10	8
	15	4
	20	0
	24	20
	29	16
Aug.	3	12
	8	7
	13	3
	17	23
	22	19
	27	15

RX Herculis.

	d	h
July	1	13
	3	8
	5	3
	6	21
	8	16
	10	11
	12	6
	14	0
	15	19
	17	14
	19	8
	21	3
	22	22
	24	16
	26	11
	28	6
	30	0

RX Herculis.

	d	h
July	31	19
Aug.	2	14
	4	8
	6	3
	7	22
	9	17
	11	11
	13	6
	15	1
	16	19
	18	14
	20	9
	22	3
	23	22
	25	17
	27	11
	29	5
	31	0

RV Lyræ.

	d	h
July	6	21
	14	2
	21	7
	28	12
Aug.	4	16
	11	21
	19	2
	26	7

U Sagittæ.

	d	h
July	3	7
	10	1
	16	20
	23	14
	30	8
Aug.	6	2
	12	21
	19	15
	26	9

SY Cygni.

	d	h
July	6	19
	18	19
	30	20
Aug.	11	20
	23	20

SW Cygni.

	d	h
July	5	4
	14	8
	23	11
Aug.	1	15
	10	18
	19	22
	29	1

Minima of Variable Stars of the Algol Type.—Continued.

UW Cygni.			UW Cygni.			W Delphini.			Y Cygni.			Y Cygni.		
	d	h		d	h		d	h		d	h		d	h
July	5	22	Aug.	30	3	Aug.	30	14	July	20	23	Aug.	13	22
	12	20	W Delphini.			Y Cygni.				23	23		16	22
	19	17	July	3	22	July	3	0		26	23		19	22
	26	15		13	12		6	0		29	23		22	22
Aug.	2	13		23	3		8	23	Aug.	1	23		25	22
	9	10	Aug.	1	18		11	23		4	23		28	22
	16	8		11	9		14	23		7	23		31	22
	23	5		20	23		17	23		10	22			

Maxima of UY Cygni.

Period $13^h\ 27^m\ 21^s$. The minimum occurs $1^h\ 53^m$ before the maximum.

		h			h			h			h
July	1	20	July	17	13	Aug.	1	3	Aug.	16	19
	2	23		18	16		2	5		17	22
	4	2		19	19		3	8		19	1
	5	5		20	21		4	11		20	4
	6	8		22	0		5	14		21	7
	7	11		23	3		6	17		22	10
	8	13		24	6		7	20		23	13
	9	16		25	9		8	23		24	16
	10	19		26	12		10	2		25	19
	11	22		27	15		11	5		26	22
	13	1		28	18		12	8		28	0
	14	4		29	21		13	11		29	3
	15	7		31	0		14	14		30	6
	16	10					15	16		31	9

Maxima of SZ Cygni will occur July 8 at 19^h, July 23 at 21^h, Aug. 7 at 23^h and Aug. 23 at 1^h.

Maxima of U Pegasi.

Period $4^h\ 29^m.8$. The minimum occurs $2^h\ 15^m$ after the maximum.

	d	h		d	h		d	h		d	h
July	1	1	July	17	4	Aug.	1	4	Aug.	16	3
	2	4		18	2		2	2		17	2
	3	2		19	1		3	1		18	0
	4	1		20	4		4	4		19	3
	5	4		21	2		5	2		20	2
	6	2		22	1		6	0		21	0
	7	1		23	4		7	3		22	3
	8	4		24	2		8	2		23	2
	9	2		25	1		9	0		24	0
	10	1		26	4		10	3		25	3
	11	4		27	2		11	2		26	2
	12	2		28	1		12	0		27	0
	13	1		29	4		13	3		28	3
	14	4		30	2		14	2		29	2
	15	2		31	1		15	0		30	0
	16	1								31	3

Maxima of Y Lyræ will occur at about 3^h A. M. during the first week in July, about 4^h A. M. during the second week, and during the remainder of July and August the maxima will occur in daylight.

Large Projection on Mars.—A telegram from Professor E. C. Pickering announces that on May 26 a large projection was observed on the terminator of Mars in position angle two hundred degrees. The projection was noticed first at eight hours thirty-five minutes, Mountain Standard time, and lasted thirty-five minutes.

Variable Stars of Short Period not of the Algol Type.

	Minimum.		Maximum.			Minimum.		Maximum	
		h		h			h		h
W Sagittarii	July 1	0	July 4	0	η Aquilae	July 15	0	July 17	6
V Carinae	1	5	3	9	T Vulpeculae	15	1	16	10
U Vulpeculae	1	10	3	13	T Velorum	15	14	16	23
W Carinae	1	11	2	11	S Triang. Austr.	15	18	17	20
T Vulpeculae	1	18	3	3	W Sagittarii	16	4	19	4
RV Scorpii	2	5	3	15	T Crucis	16	15	18	16
T Monocerotis	2	5	10	3	X Cygni	16	19	23	14
κ Pavonis	2	12	6	7	S Normae	16	21	21	7
Y Sagittarii	3	2	4	21	SU Cygni	17	7	18	15
S Trianguli Austr.	3	2	5	4	U Vulpeculae	17	9	19	12
S Sagittae	3	2	6	12	β Lyrae	17	18	21	1
V Centauri	3	3	4	14	R Crucis	17	19	19	4
T Crucis	3	3	5	4	U Aquilae	18	11	20	15
δ Cephei	3	10	5	1	X Sagittarii	18	18	21	15
U Aquilae	4	10	6	14	W Carinae	18	23	19	22
X Sagittarii	4	17	7	14	U Sagittarii	19	9	22	8
β Lyrae	4	20	8	3	T Vulpeculae	19	11	20	20
S Muscae	4	23	8	10	δ Cephei	19	13	21	4
S Crucis	5	14	7	2	V Centauri	19	15	21	2
SU Cygni	5	18	7	2	S Crucis	19	16	21	4
W Carinae	5	20	6	19	S Sagittae	19	20	23	6
U Sagittarii	5	21	8	20	T Velorum	20	5	21	15
R Crucis	6	3	7	12	RV Scorpii	20	9	21	19
T Vulpeculae	6	4	7	13	Y Sagittarii	20	10	22	5
T Velorum	6	7	7	16	κ Pavonis	20	17	24	12
TX Cygni	6	8	11	11	TX Cygni	21	1	26	4
S Normae	7	3	11	13	SU Cygni	21	3	22	11
η Aquilae	7	19	10	1	V Carinae	21	7	23	11
V Carinae	7	21	10	1	S Triang. Austr.	22	1	24	3
RV Scorpii	8	6	9	16	η Aquilæ	22	4	26	10
W Sagittarii	8	14	11	14	W Carinae	23	8	24	7
V Centauri	8	15	10	2	T Crucis	23	8	25	9
δ Cephei	8	19	10	10	R Crucis	23	15	25	0
Y Sagittarii	8	21	10	16	W Sagittarii	23	19	26	19
S Trianguli Austr.	9	10	11	12	T Vulpeculae	23	22	25	7
U Vulpeculae	9	10	11	13	β Lyrae	24	5	27	7
SU Cygni	9	14	10	22	S Muscae	24	7	27	18
T Crucis	9	21	11	22	S Crucis	24	9	25	21
W Carinae	10	5	11	4	T Velorum	24	21	26	6
S Crucis	10	7	11	19	δ Cephei	24	22	26	13
T Vulpeculae	10	15	12	0	V Centauri	25	3	26	14
T Velorum	10	22	12	8	U Vulpeculae	25	9	27	12
Y Ophiuchi	11	6	17	11	U Aquilae	25	12	27	16
β Lyrae	11	7	14	9	X Sagittarii	25	18	28	16
S Sagittae	11	11	14	21	U Sagittarii	26	3	29	2
U Aquilae	11	11	13	15	Y Sagittarii	26	4	27	23
κ Pavonis	11	15	15	10	RV Scorpii	26	11	28	21
X Sagittarii	11	17	14	14	S Normae	26	15	31	1
R Crucis	11	23	13	8	W Carinae	27	17	28	16
U Sagittarii	12	15	15	14	V Carinae	27	23	30	3
SU Cygni	13	11	14	19	S Sagittae	28	5	31	15
V Centauri	14	3	15	14	T Vulpeculæ	28	8	29	17
δ Cephei	14	4	15	19	S Triang. Austr.	28	9	30	11
W Virginis	14	5	22	10	Y Ophiuchi	28	9	Aug. 3	14
RV Scorpii	14	8	15	18	SU Cygni	28	20	30	4
W Carinae	14	14	15	13	S Crucis	29	1	30	13
V Carinae	14	14	16	18	T Monocerotis	29	6	Aug. 6	4
Y Sagittarii	14	15	16	10	η Aquilae	29	8	31	14
S Muscae	14	15	19	2	R Crucis	29	11	30	20
S Crucis	15	0	16	12	T Velorum	29	12	30	21

Variable Stars of Short Period not of the Algol Type.—Continued.

	Minimum.	h	Maximum.	h		Minimum.	h	Maximum.	h
κ Pavonis	July 29	19	Aug. 2	14	RV Scorpii	Aug. 13	15	Aug. 15	1
β Lyræ	30	16	2	23	S Sagittae	14	0	17	10
T Crucis	30	2	1	3	W Carinae	14	5	15	4
δ Cephei	30	6	31	21	Y Ophiuchi	14	12	20	17
V Centauri	30	15	1	2	T Vulpeculae	15	2	16	11
W Sagittarii	31	9	3	9	S Normae	15	3	19	13
W Virginis	31	11	8	16	U Sagittarii	15	8	18	7
Y Sagittarii	31	23	2	18	δ Cephei	15	9	17	0
W Carinae	Aug. 1	2	Aug. 2	1	W Sagittarii	15	13	18	13
RV Scorpii	1	12	2	22	ζ Geminorum	15	13	20	13
X Sagittarii	1	18	4	15	U Aquilae	15	14	17	18
U Sagittarii	1	21	4	20	X Sagittarii	15	19	18	16
U Aquilae	1	13	3	17	R Crucis	15	23	17	8
SU Cygni	1	16	3	0	V Centauri	16	3	17	14
T Vulpeculæ	1	19	3	4	S Triang. Austr	16	8	18	10
X Cygni	2	4	8	23	S Crucis	16	19	18	7
U Vulpeculæ	2	8	4	11	κ Pavonis	16	23	20	18
S Crucis	2	18	4	6	V Carinae	17	1	19	5
S Muscae	2	22	6	9	T Velorum	17	1	18	10
T Velorum	3	3	4	12	W Virginis	17	18	25	23
W Geminorum	3	7	5	22	Y Sagittarii	18	7	20	2
V Carinae	3	16	5	20	U Vulpeculae	18	7	20	10
S Trianguli Austr.	3	17	5	19	W Carinae	18	13	19	12
R Crucis	4	7	5	16	X Cygni	18	13	25	8
W Carinæ	4	11	5	10	β Lyrae	19	1	22	3
δ Cephei	4	15	6	6	T Crucis	19	6	21	7
TX Cygni	4	19	9	22	T Vulpeculae	19	13	20	22
V Centauri	5	3	6	14	TX Cygni	19	13	24	16
S Normae	5	9	9	19	RV Scorpii	19	17	21	3
SU Cygni	5	12	6	20	η Aquilae	19	21	22	3
η Aquilae	5	12	7	18	δ Cephei	20	17	22	8
S Sagittae	5	14	9	0	SU Cygni	20	22	22	6
T Crucis	5	19	7	20	S Crucis	21	11	22	23
β Lyræ	6	3	9	5	V Centauri	21	14	23	1
T Vulpeculae	6	5	7	14	T Velorum	21	17	23	2
Y Sagittarii	6	18	8	13	R Crucis	21	18	23	3
S Crucis	7	10	8	22	U Sagittarii	22	2	25	1
RV Scorpii	7	14	9	0	S Muscae	22	6	25	17
T Velorum	7	18	9	4	S Sagittae	22	9	25	19
κ Pavonis	7	21	11	16	U Aquilae	22	14	24	18
W Sagittarii	7	23	10	23	S Triang. Austr.	22	16	24	18
U Aquilae	8	13	10	17	X Sagittarii	22	19	25	16
U Sagittarii	8	15	11	14	W Carinae	22	22	23	21
X Sagittarii	8	18	11	15	W Sagittarii	23	4	26	4
W Carinae	9	20	10	19	V Carinae	23	18	25	22
δ Cephei	10	0	11	15	T Vulpeculae	23	23	25	8
S Trianguli Austr.	10	1	12	3	Y Sagittarii	24	1	25	20
R Crucis	10	2	11	11	SU Cygni	24	18	26	2
U Vulpeculae	10	8	12	11	S Normae	24	22	29	8
V Carinae	10	9	12	13	T Monocerotis	25	6	33	4
V Centauri	10	15	12	2	β Lyrae	25	12	28	19
T Vulpeculæ	10	16	12	1	ζ Geminorum	25	17	30	17
W Geminorum	11	1	13	16	RV Scorpii	25	18	27	4
S Crucis	12	3	13	15	T Crucis	26	0	28	1
T Velorum	12	10	13	19	δ Cephei	26	2	27	17
Y Sagittarii	12	12	14	7	κ Pavonis	26	2	29	21
T Crucis	12	13	14	14	S Crucis	26	4	27	16
S Muscae	12	14	18	1	U Vulpeculae	26	7	28	10
β Lyræ	12	14	15	21	T Velorum	26	8	27	17
η Aquilæ	12	17	14	23	η Aquilae	27	1	29	7
SU Cygni	13	5	14	13	V Centauri	27	3	28	14

Variable Stars of Short Period not of the Algol Type.—Continued.

	Minimum.		Maximum.			Minimum.		Maximum.	
		h		h			h		h
W Carinae	Aug. 27	7	Aug. 28	6	W Sagittarii	Aug. 30	18	Aug. 33	18
R Crucis	27	14	28	23	S Sagittae	30	18	34	4
T Vulpeculae	28	10	29	19	S Crucis	30	21	32	9
SU Cygni	28	14	29	22	T Velorum	30	23	32	8
U Sagittarii	28	20	31	19	δ Cephei	31	11	33	1
S Triang. Austr.	29	0	31	2	Y Ophiuchi	31	15	37	20
U Aquilae	29	15	31	19	RV Scorpii	31	20	33	6
X Sagittarii	29	19	32	16	S Muscae	31	22	35	9
Y Sagittarii	29	20	31	15	β Lyrae	31	23	35	1
V Carinae	30	11	32	15					

Maxima and Minima of Long Period Variables.

[Computed from Chandler's "Third Catalogue." A question mark indicates that the elements are in doubt. By Misses Ida I. Watson and Helen M. Swartz of Vassar College Observatory.]

Maxima.

Date	No.	Star.
Aug.		
1	1771	R Leporis
2	5931	S Ophiuchi
4	5194	V Bootis
8	3994	S Leonis
9	5190	R Camelopardalis
10	513	R Piscium
11	2857	U Puppis
11	8230	S Aquarii
13	7560	R Vulpeculae
15	6943?	T Sagittae
16	7242	S Aquilae
17	7754	W Cygni
18	5583	X Librae
18	5677	R Serpentis
23	103	T Andromedae
24	7468	T Aquarii
25	434	S Piscium
25	8153	R Lacertae
30	8068	S Lacertae
31	466	V Piscium
31	5704	RR Librae
Sept.		
2	893	U Ceti
4	2530	V Canis Minoris
4	2742	S Geminorum
5	5758	X Herculis
9	7260?	Z Aquilae
10	513	R Piscium
11	1222	R Persei
12	1386	T Eridani
12	2735	U Canis Minoris
12	5831	S Scorpii
14	114	S Ceti
16	3477	R Leonis Minoris
16	7455	U Capricorni
17	7444	T Delphini
17	1511	T Ursae Majoris

Maxima.

Date.	No.	Star.
Sept.		
18	7456?	RR Cygni
18	7659	T Capricorni
20	1981	S Camelopardalis
22	5037	RR Virginis
22	5237	R Bootis
25	1803?	T Leporis
25	4557	S Ursae Majoris
26	7571	V Capricorni
28	1113	U Arietis
29	5430	T Librae
30	845	R Ceti
30	4521	R Virginis
30	7045	R Cygni

Minima.

Aug.		
3	2684	R Canis Minoris
9	906	R Trianguli
12	6512	T Herculis
22	5338	U Bootis
25	4596	U Virginis
26	7085	RT Cygni
28	8324	V Cassiopeiae
28	8373	S Pegasi
29	1623	T Camelopardalis
Sept.		
2	4826	R Hydrae
7	6921	S Sagittarii
7	1717	V Tauri
8	7576	X Capricorni
12	782	R Arietis
18	112	R Andromedae
19	5675	V Coronae
19	6905	R Sagittarii
20	7431	S Delphini
23	2946	R Cancri
24	7609	T Cephei
26	5887	V Ophiuchi

Approximate Magnitudes of Variable Stars May 10, 1903.

[Communicated by the Director of Harvard College Observatory, Cambridge, Mass.]

Name.	R. A. 1900.		Decl. 1900.		Magn.	Name.	R. A. 1900.		Decl. 1900.		Magn.
	h	m	°	′			h	m	°	′	
T Androm.	0	17.2	+ 26	26	*u*	R Camel.	14	25.1	+ 84	17	12*d*
T Cassiop.	0	17.8	+ 55	14	12	R Bootis	14	32.8	+ 27	10	12*d*
R Androm.	0	18.8	+ 38	1	*u*	S Librae	15	15.6	− 20	2	8*i*
S Ceti	0	19.0	− 9	53	*s*	S Serpentis	15	17.0	+ 14	40	12
W Cassiop.	0	49.0	+ 58	1	*u*	S Coronae	15	17.3	+ 31	44	9*d*
S "	1	12.3	+ 72	5	8*i*	S Urs. Min.	15	33.4	+ 78	58	9*d*
R Piscium	1	25.5	+ 2	22	*s*	R Coronae	15	44.4	+ 28	28	7
R Trianguli	1	31.0	+ 33	50	10*d*	V "	15	45.9	+ 39	52	*u*
U Persei	1	52.9	+ 54	20	11*d*	R Serpentis	15	46.1	+ 15	26	*f*
R Arietis	2	10.4	+ 24	36	*s*	R Herculis	16	1.7	+ 18	38	*f*
o Ceti	2	14.3	− 3	26	*s*	R Scorpii	16	11.7	− 22	42	*u*
S Persei	2	15.7	+ 58	8	9*d*	S "	16	11.7	− 22	39	*u*
R Ceti	2	20.9	− 0	38	*s*	U Herculis	16	21.4	+ 19	7	10*d*
U "	2	28.9	− 13	35	*s*	R Ursae Min.	16	31.3	+ 72	28	10*d*
R Persei	3	23.7	+ 35	20	*u*	W Herculis	16	31.7	+ 37	32	9*d*
R Tauri	4	22.8	+ 9	56	*s*	R Draconis	16	32.4	+ 66	58	10*i*
S "	4	23.7	+ 9	44	*s*	S Herculis	16	47.4	+ 15	7	11*d*
R Aurigæ	5	9.2	+ 53	28	11*d*	R Ophiuchi	17	2.0	− 15	58	12*d*
U Orionis	5	49.9	+ 20	10	6	T Herculis	18	5.3	+ 31	0	10*i*
R Lyncis	6	53.0	+ 55	28	*f*	R Scuti	18	42.2	− 5	49	*u*
R Gemin.	7	1.3	+ 22	52	12*i*	R Aquilae	19	1.6	+ 8	5	*u*
S Canis Min.	7	27.3	+ 8	32	9*d*	R Sagittarii	19	10.8	− 19	29	*u*
R Cancri	8	11.0	+ 12	2	11*d*	S "	19	13.6	− 19	12	*u*
V "	8	16.0	+ 17	36	9*i*	R Cygni	19	34.1	+ 49	58	*f*
S Hydrae	8	48.4	+ 3	27	8*i*	RT "	19	40.8	+ 48	32	8
T "	8	50.8	− 8	46	7	X "	19	46.7	+ 32	40	*f*
R Leo. Min.	9	39.6	+ 34	58	13*d*	S Cygni	20	3.4	+ 57	42	*f*
R Leonis	9	42.2	+ 11	54	9*i*	RS "	20	9.8	+ 38	28	8*i*
R Urs. Maj.	10	37.6	+ 69	18	13*f*	R Delphini	20	10.1	+ 8	47	13*f*
R Comae	11	59.1	+ 19	20	*f*	U Cygni	20	16.5	+ 47	35	7
T Virginis	12	9.5	− 5	29	12*d*	V "	20	38.1	+ 47	47	11*d*
R Corvi	12	14.4	− 18	42	9*d*	T Aquarii	20	44.7	− 5	31	13*f*
Y Virginis	12	28.7	− 3	52	*f*	R Vulpec.	20	59.9	+ 23	26	8
T Urs. Maj.	12	31.8	+ 60	2	12*d*	T Cephei	21	8.2	+ 68	5	8*d*
R Virginis	12	33.4	+ 7	32	7	S "	21	36.5	+ 78	10	10*d*
S Urs. Maj.	12	39.6	+ 61	38	10*d*	S Lacertae	22	24.6	+ 39	48	*u*
U Virginis	12	46.0	+ 6	6	8	R "	22	38.8	+ 41	51	*u*
V "	13	22.6	− 2	39	9*d*	S Aquarii	22	51.8	− 20	53	*s*
R Hydrae	13	24.2	− 22	46	7*d*	R Pegasi	23	1.6	+ 10	0	*u*
S Virginis	13	27.8	− 6	41	*f*	S "	23	15.5	+ 8	22	*u*
R Can. Ven.	13	44.6	+ 40	2	10*i*	R Aquarii	23	38.6	− 15	50	*s*
S Bootis	14	19.5	+ 54	16	11*d*	R Cassiop.	23	53.3	+ 50	50	11*d*

NOTE:—*f* denotes that the variable is probably fainter than the magnitude 13; *i*, that its light is increasing; *d*, that its light is decreasing; *s*, that it is near the Sun; *u*, that its magnitude is unknown.

Nova Geminorum, 12.1903.—The new star is now getting pretty low in the west for satisfactory observation in the evening, yet it may be followed probably for about a month longer. On May 20 the writer made the estimate

c 10 *N* 2 *e*,

using the notation on p. 259 of the May number of POPULAR ASTRONOMY. This would make the magnitude of the Nova 9.3 according to the BD., or 9.9 according to the scale adopted by Father Hagen.

Variable Star 11.1903.—The accompanying cut, a chart for the star 11.1903, was not prepared in time for insertion in our last number.

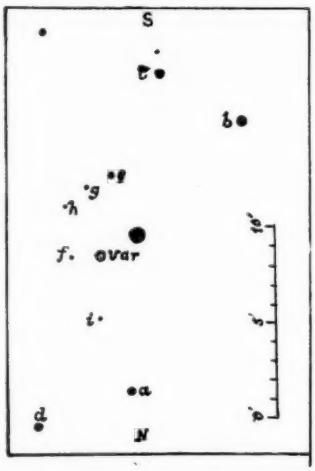


CHART OF THE VARIABLE STAR 11.1903.

The Discovery of Nova Geminorum.—Unlike the discovery of Nova Persei that of Nova Geminorum was not the result of a systematic search for new objects, but was in a sense an accidental incident in another line of research. Mr. Bellamy, in a paper read before the Royal Astronomical Society April 8 (*The Observatory*, May 1903 p. 196) says that "on March 16 he was taking some photographs in Zone 30° (this was a part of the regular work of constructing the Photograph Chart of the heavens) and he had some difficulty in 'setting.' The guiding star entered in the catalogue was of the magnitude 8.6, but there was near the place a bright star which he estimated to be a 7th mag., and he assumed that perhaps 8.6 was a mistake for 6.8. The next day he developed the plate, and the day after they examined the settings to see if they were sufficiently accurate, and this plate had to be rejected and was put aside. On March 24, Professor Turner happened to be looking over some of the recent plates and settled which were to be rejected. Taking down these rejected plates into the lecture-room Professor Turner noticed some plates rejected without reason written on the envelopes, and he enquired why they were there with no note on them. He was told that this particular plate had a wrong setting, and thereupon compared it with an overlapping plate to see how the mistake arose, and saw at once that the star which had been used for guiding the telescope was not on this other plate." The resulting investigation of other plates led to the discovery.

On page 225 of the May number of *The Observatory* Professor Turner under the heading "From an Oxford Note-Book" makes the following interesting comments:

"We in Oxford have naturally felt gratified that a new star should have chosen us as the medium of revelation. Anything more unexpected than a Nova offering itself as a guiding-star to a man about to expose a plate could scarcely

be imagined. I hope it will be understood that we have no right to the acclamation which would naturally follow a successful *search*. If the discovery had fallen to Harvard (as it apparently might have fallen quite naturally on t' e scrutiny of a plate taken on March 25), it would have been the legitimate result of a systematic search which Professor Pickering has undertaken with immense courage and resource; and he might have been justly proud of his success, as he and Mrs. Fleming have reason to be proud of their many previous successes in this field. Indeed they have ample reason to complain of Fortune for robbing them of their legitimate spoils, and if we could rise above human nature for a moment, we might perhaps feel sorry that we had the good luck to take that plate at Oxford; for it was indeed the purest of accidents. And a curious thing is that we should never have taken the photograph at all but for a *batch of bad plates* which were supplied us. Our excellent plate-makers, Messrs. Elliott Bros., who had never given us anything but complete satisfaction before, in some unaccountable way sent us a batch of inferior plates. We were just then very hard at work trying to finish the last hundred of our zone, and we took 20 or 30 plates straight on end before we found ont the trouble, including the critical region $6^h\ 30^m + 30°$. Had the plates been good, that region would have been "cleared off." But on developing the plates we found, to our mortification, that they were poor and must be taken again. Messrs. Elliott were deeply concerned, and supplied us with better plates at once, and we went over the ground again, groaning at the loss of time. Meantime the Nova had blazed up, and appeared on the second edition of the region $6^h\ 36^m + 30°$! We all know the old proverb about an "ill wind," but I am indebted to Lady Huggins for the following apt Shakespearian quotation. There is

> some soul of goodness in things evil
> Would men *observingly* distil it out."

Chart and Catalogue for Observing Nova Geminorum.—Father John J. Hagen, of the Georgetown College Observatory, has prepared a chart and catalogue for observing Nova Geminorum, similar to that which proved so useful in the case of Nova Persei. For the sake of our readers who may wish to follow the changes of this new star we reproduce here the chart and catalogue.

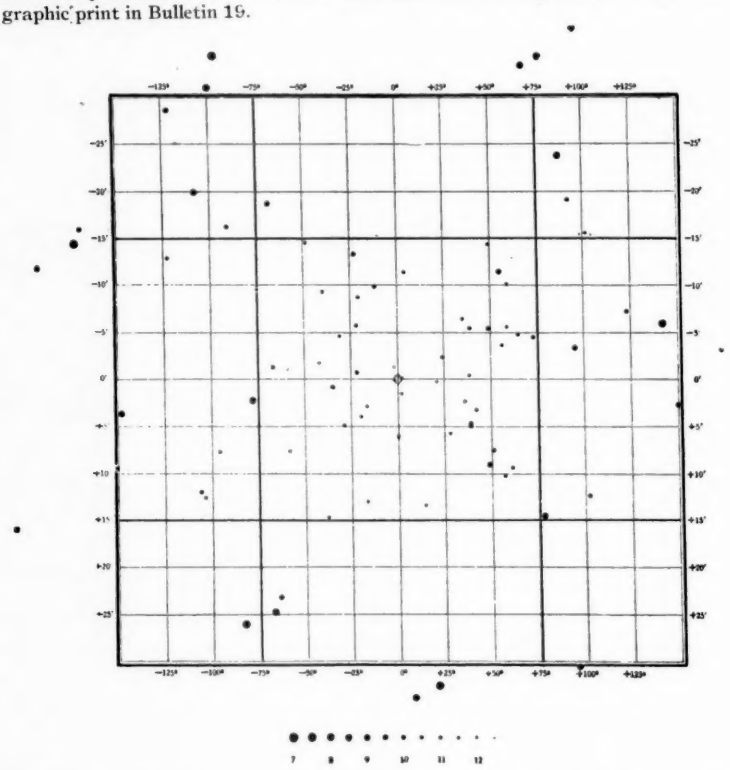
EXPLANATIONS.

The extended use which has been made of the two charts and catalogues for observing Nova Persei is ample proof that the labor and expense involved in preparing and publishing a similar Circular for Turner's Nova would be fully justified. These charts and catalogues afford easy identifications and short designations of the comparison stars, and give the basis for any magnitude scale over the whole region covered by them. They are in fact a *Durchmusterung* on a small scale, and exhibit all the stars within definite limits.

The present chart, like the second for Nova Persei, has three different limits of magnitudes, or densities of stars. The large square, measuring one degree in both dimensions, gives all the BD. stars; a smaller concentric square, half a degree wide, contains all the stars visible in our twelve-inch refractor with a low power; and a still smaller concentric region, of 10′ width, all those visible in a higher power; besides three stars not seen here but assured by two independent publications, the H. C. O. Circular No. 70 and the Y. O. Bulletin No. 19.

The *positions* of the stars are not all through as accurate as those in the Atlas of Variable Stars, since the few good nights that were available had to be

spent in establishing the relative magnitude scale. The brighter stars could be taken from the Cambridge and Leiden Zones of the A. G. C. (assuming Professor Barnard's position of the Nova in Bulletin 19); the fainter stars were measured here in strong moon light, while the faintest had to be taken partly from the measures published in the Circular above mentioned and partly from a photographic print in Bulletin 19.



The *magnitudes*, however, are more exact than those in the Atlas generally, because special care was taken in their estimates. The scale of steps was observed independently on two or three different nights, and was then graphically reduced to magnitudes by means of some standard measures kindly furnished by Professor Pickering.

NOVA GEMINORUM.

(1900.0) $6^h\ 37^m\ 49^s.0$, $(+\ 3^s.83)$ $+\ 30°\ 2'.6$ $(-\ 0'.06)$.

No.	Steps.	Magn.		BD.	$\Delta\alpha$	$\Delta\delta$		Notes.	
		m	m	°	m s	′		m	
1	0	7.3	7.2	+ 29 1307	− 2 53	− 14.4	HP.	7.36	C. 3424
2	7	7.5	7.8	29 1320	− 1 37	− 34.5	"	7.46	C. 3443
3	17	7.9	8.2	29 1342	+ 2 22	− 5.9	"	8.16	C. 3482
4	23	8.1	8.5	29 1332	+ 1 17	− 34.4			C. 3471
5	26	8.2	8.3	29 1336	+ 1 36	− 37.4			C. 3477

NOVA GEMINORUM.

No.	Steps.	Magn.		BD.	Δα	Δδ		Notes.	
		m	m	°	m s	′		m	
6	26	8.2	8.2	+30 1314	+0 20	+32.5	"	7.99	L. 2797
7	26	8.2	8.0	30 1300	−3 21	+15.3	"	7.88	L. 2763
8	28	8.2	8.2	30 1305	−1 23	+26.0			L. 2782
9	34	8.5	8.6	29 1319	−1 40	−31.1			C. 8441
10	38	8.6	8.7	29 1334	+1 27	−23 8			C. 3473
11	40	8.6	8.8	30 1306	−1 18	+ 2.3	"	8.76	L. 2783
12	44	8.7	8.8	30 1307	−1 7	+24.9			L. 2784
13	50	8.9	8.6	30 1313	+0 7	+33.9			L. 2794
14	52	9.0	9.0	30 1322	+1 35	+30.5			L. 2805
15	53	9.0	8.9	30 1320	+1 18	+14.6	"	8.93	L. 2803
16	56	9.1	9.1	29 1331	+1 3	−33.4			
17	57	9.1	9.0	29 1317	−1 48	−19.9			C. 3439
18	59	9.2	9.2	30 1302	+2 29	+ 3.6	"	9.34	L. 2772
19	65	9.4	9.1	29 1315	−2 6	−28.7			
20	66	9.4	9.0	30 1316	+0 49	+ 9.1	"	9.26	L. 2798
21	66	9.4	9.1	29 1305	−3 15	−11.9			
22	69	9.5	9.2	29 1328	+0 53	−11.7			
23	73	9.6	9.2	30 1321	+1 34	− 3.3			
24	74	9.6	9.3	29 1322	−1 12	−18.7			
25	78	9.8	9.3	30 1324	+2 30	+ 2.7			
26	82	9.9	9.4	29 1308	−2 50	−16.0			C. 3425
27	82	9.9	9.4	29 1324	−0 23	−13.3			C. 3455
28	86	10.0	9.5	30 1317	+0 49	− 5.4	"	10.08	
29	87	10.0	9.5	30 1328	+2 53	− 3.1			
30	90	10.1			+0 39	+ 4.8			
31	92	10.2	9.4	30 1309	−0 35	+ 0.8	"	10.13	
32	92	10.2	9.5	30 1308	−1 0	+23.2			
33	95	10.3	9.5	30 1301	−2 29	+ 9.5			
34	96	10.3			−1 45	+12.0			
35	97	10.3	9.5	29 1316	−2 5	−12.9			
36	99	10.4			−1 34	−16.2			
37	100	10.4			−1 7	− 1.3			
38	101	10.4	9.5	29 1335	+1 29	−19.1			
39	104	10.5	9.5	29 1340	+2 (2)	− 7.2			
40	105	10.5			+1 (44)	−12.4			
41	108	10.6	9.5	+30 1315	+0 38	− 5.2			
42	111	10.7			+1 13	− 4.5			
43	112	10.7			−0 12	− 9.9			
44	113	10.7			−0 24	− 0.8	"	10.78	
45	114	10.8			−1 35	+ 7.8			
46	117	10.8			−1 (42)	+12.6			
47	119	10.9			−0 22	− 5.7			
48	120	10.9			+0 0	+ 6.1			
49	120	10.9			+0 39	+ 5.0			
50	123	11.0			+0 42	+ 3.8	"	11.10	
51	123	11.0			+0 4	−11.4			
52	126	11.0			−0 21	− 8.7			
53	130	11.1			−0 40	− 9.3			
54	130	11.1			+0 51	+ 7.6			
55	132	11.1			−0 49	−14.5			

NOVA GEMINORUM.

No.	Steps.	Magn.	BD.	Δα	Δδ	Notes.
		m m	°	m s	′	m
56	133	11.2		+ 0 24	— 2.3	" 10.95
57	136	11.2		+ 1 1	+ 1.4	
58	139	11.3		— 0 42	— 9.7	
59	140	11.3		— 1 15	— 9.6	
60	143	11.3		+ 0 57	+ 10.3	
61	143	11.3		— 0 31	— 4.6	" 11.32
62	146	11.4		+ 0 35	— 6.4	
63	147	11.4		+ 0 38	— 0.4	
64	147	11.4		— 0 38	+ 14.7	
65	149	11.5		+ 0 59	— 10.1	
66	149	11.5		— 0 29	+ 4.9	
67	149	11.5		+ 0 14	+ 13.4	
68	152	11.5		— 0 17	+ 13.0	
69	152	11.5		— 0 58	+ 7.7	
70	152	11.5		+ 0 59	— 5.5	
71	155	11.6		+ 0 49	— 14.3	
72	156	11.6		+ 0 56	— 3.6	
73	156	11.6		— 0 17	+ 2.9	
74	159	11.7		+ 1 5	— 4.7	
75	159	11.7		+ 0 21	+ 0.3	
76	160	11.7		+ 0 28	+ 5.7	
77	164	11.7		— 0 20	+ 4.0	
78	165	11.7		+ 0 36	+ 2.4	
79				+ 0 2	+ 1.6	H. C. 70 α, Y. Bull. 19, No. 6
80				— 0 2	— 1.4	" β, " " " 4
81				+ 0 2	— 0.1	" γ, " " " 1

Nova Persei.

Star.	Y. M. D.	H. M.	J. Day.	Comparison.	
Nova Persei	1903 3 17	7 20	2416191	*q* 4 V 2 *r*	
" "	" " "	7 35	"	*q* 4 V 1½ *r*	
" "	" " 18	7 0	6192	*q* 4 V 2 *r*	
" "	" " 25	7 30	6199	*q* 4 V 2 *r*	
" "	" " 29	6 50	6203	*q* 4 V 1½ *r*	Twilight.
" "	" " 31	6 55	6205	*q* 4 V 1¼ *r*	"
" "	" 4 1	6 50	6206	*q* 4½ V 1½ *r*	"
" "	" " 5	7 15	6210	*q* 4½ V 1½ *r*	
" "	" " 12	6 55	6217	*q* 4 V 2 *r*	Twilight.
" "	" " 18	8 10	6223	*q* 4½ V 1 *r*	
" "	" " 19	7 10	6224	*q* 4½ V 1 *r*	
" "	" " 20	7 15	6225	*q* 4½ V 1 *r*	
" "	" " 21	7 40	6226	*q* 4½ V 1½ *r*	
" "	" " 25	8 5	6230	*q* 4 V 1½ *r*	

The Nova is still declining very slowly. I estimate it now at 10.4 magnitude.

F. E. SEAGRAVE.

Radial Velocities of δ Aquilae and φ Persei.—In the *Bulletin Astronomique* for April, 1903, M. H. Deslandres of the Observatory of Meudon, France, gives the results obtained with the great double refractor at Meudon, in spectrographic research during the years 1901-2 on the radial velocities of the

stars δ Aquilae and φ Persei. Both of these stars are white and are not known to be variable, but they must be classed with the spectroscopic binaries.

MEASURED RADIAL VELOCITY OF δ AQUILÆ.

	km.		km.
1901 July 2	— 3.3	1902 Oct. 17	— 59.8?
17	+ 20.4	24	— 37.6
1902 Aug. 2	— 15.6	25	— 20.8
7	— 50.1	29	+ 24.9
9	— 60.1	31	— 58.5
20	— 19.8	Nov. 3	— 62.4
27	— 54.4	15	— 4.1
Sept. 17	— 53.3	17	— 39.5
18	— 50.3	18	— 63.5
19	— 57.4	22	— 61.1
22	— 39.2	Dec. 2	— 12.4
27	— 35.6	4	— 29.4
Oct. 6	— 45.0?	11	— 68.5

The period of δ Aquilæ appears to be about 16.7 days and the orbit has an eccentricity of about 0.60.

MEASURED RADIAL VELOCITY OF φ PERSEI.

	km.		km.
1899 Oct. 14	— 15.2	1902 Aug. 25	+ 5.6
1902 Feb. 21	+ 3.2	28	+ 4.0
Mar. 6	— 20.	Sept. 1	+ 11.0

This star has a curious spectrum in which the hydrogen lines are white with a central reversal, which indicates an atmosphere relatively a good deal more intense than the solar atmosphere.

New Variable 15.1903 Cephei.—This is announced in *A. N.* 3863 and was discovered by Mme. Ceraski on the photographs taken by M. S. Blajko at Moscow. Its position is

1855.0	R. A. 2^h $07^m.1$;	Decl. + 81° 00′
1900.0	2 12 .8	+ 81 13

Its period is several months and the variation is from about $9^m.5$ at maximum to below $12^m.5$ at minimum.

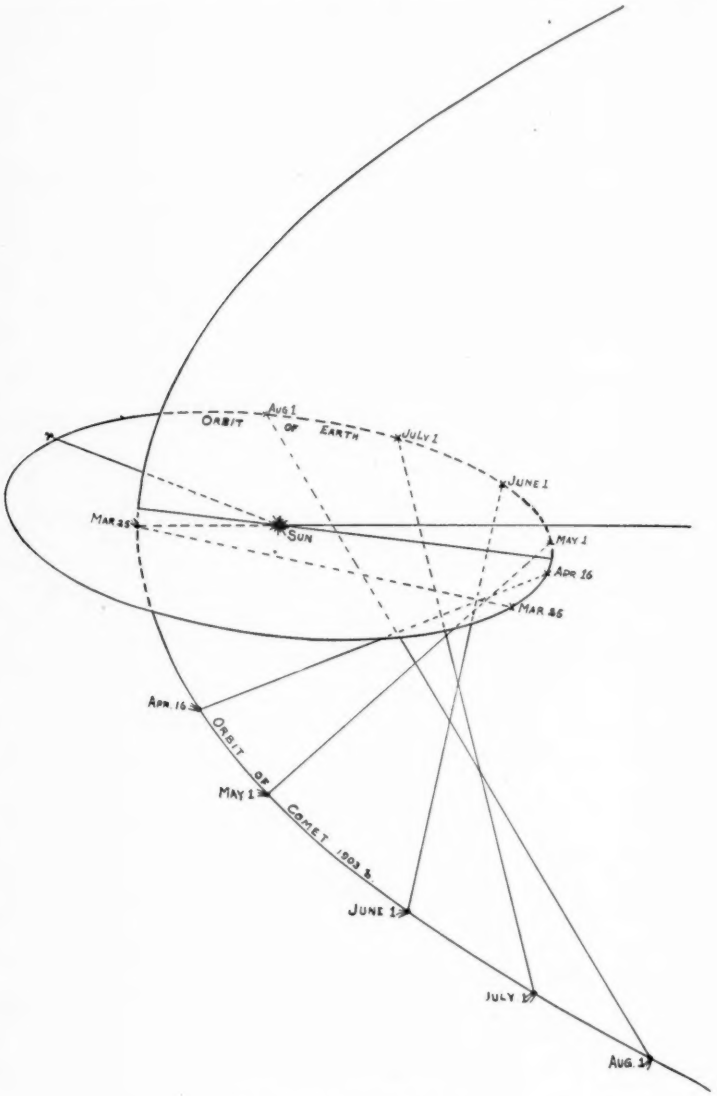
New Variable 16.1903.—This was also discovered by Mme. Ceraski, and was of the 9.3 magnitude upon a photograph taken in February, 1899. On other photographs it is fainter and at present it is invisible at Moscow, that is, it is below 13^m. Its position is

1855.0	R. A. 7^h $10^m.0$;	Decl. + 1° 22′
1900.0	7 12 .1	+ 1 18

COMET AND ASTEROID NOTES.

New Comet 1903 *b*.—A comet was discovered by Grigg at Thames, New Zealand, April 16.792, Gr. M. T., in R. A. 3^h 7^m and Decl. — 11° 06′. The following positions were determined by Tebbutt, at Windsor, N. S. Wales:

Gr. M. T.	R. A.			Decl.		
	h	m	s	°	′	″
Apr. 26.8617	4	3	1.6	— 16	23	25
27.8629	4	8	45.6	— 16	50	10
29.8642	4	20	12.5	— 17	41	4
May 1.8520	4	31	32.9	— 18	28	15



ORBIT OF COMET 1903 *b*.

From these observations Mr. M. Ebell, of Kiel, Germany, has computed the following elements:

$$T = 1903 \text{ March } 25.5486 \text{ Berlin M. T.}$$
$$\omega = 186^\circ\ 40'.7$$
$$\Omega = 213\ \ 14\ .5$$
$$i = 66\ \ 29\ .6$$
$$\log q = 9.71054$$

The accompanying diagram, prepared by means of the above elements shows the relative movement of the comet and Earth from Mar. 25, the date of perihelion to Aug. 1, when it will pretty certainly cease to be visible. No statement is given in the telegrams of announcement as to the brightness of the comet but it is not likely to be very brilliant and, according to the ephemeris, is rapidly growing fainter. It is not and probably will not be in position to be observed at the northern observatories.

Ephemeris of Comet 1903 *b*.

Berlin midn.	R. A.			Decl.		log *r*	log Δ	Br.
	h	m	s	°	′			
May 1	4	29	22	−18	19.4	9.9865	0.1441	0.83
5	4	52	06	−19	46.4	0.0160	0.1498	0.71
9	5	14	33	−21	00.6	0.0435	0.1574	0.60
13	5	36	33	−22	02.8	0.0692	0.1668	0.51
17	5	57	59	−22	53.9	0.0934	0.1779	0.43
21	6	18	40	−23	34.9	0.1161	0.1905	0.37
25	6	38	34	−24	07.2	0.1375	0.2042	0.31
29	6	57	34	−24	32.2	0.1578	0.2190	0.27
June 2	7	15	40	−24	51.2	0.1769	0.2345	0.23

Ephemeris of Comet 1903, *a*, CONTINUED FROM PAGE 268.

Paris Midn. 1903.	R. A.			Decl.		log *r*.	log Δ.	Brightness.
	h	m	s	°	′			
July 5	14	42	54	−67	37.4			
6		43	48	67	15.5	0.3471	0.1829	0.4
7		44	44	66	54.0			
8		45	42	66	32.9			
9		46	42	66	12.2			
10		47	43	65	51.9	0.3584	0.2048	0.4
11		48	46	65	31.9			
12		49	50	65	12.3			
13		50	55	64	53.1			
14		52	2	64	34.2	0.3694	0.2262	0.3
15		53	10	64	15.7			
16		54	19	63	57.6			
17		55	29	63	39.8			
18		56	40	63	22.3	0.3799	0.2472	0.3
19		57	52	63	5.2			
20	14	59	5	62	48.3			
21	15	0	19	62	31.8			
22		1	33	62	15.6	0.3901	0.2677	0.2
23		2	49	61	59.8			
24		4	5	61	44.2			
25		5	22	61	28.9			
26		6	39	61	13.9	0.3999	0.2877	0.2
27		7	57	60	59.2			
28		9	16	60	44.8			
29		10	36	60	30.7			
30	15	11	56	−60	16.9	0.4095	0.3073	0.2

Ephemeris of Faye's Comet.—This ephemeris of Faye's comet is based upon the elements published in a recent number of the *Astronomische Nachrichten* by Professor Stromgren. The comet will be in perihelion June 3d. It will then be very *unfavorably* situated for observations, as it will be beyond the Sun and will rise only about fifty minutes before him in the morning. It should be seen about the middle of July, as it will then rise about an hour and fifty minutes before the Sun, and its distance from the Earth will be less. F. E. SEAGRAVE.

Ephemeris of Faye's Comet.

Greenwich Midnight. 1903.	α h	m	s	δ °	′	″	log *r*	log Δ
June 3	3	34	17	+16	59	44	0.217411	0.413842
7	3	46	15	+17	23	35	0.217534	0.412605
11	3	58	13	+17	44	23	0.217915	0.411446
15	4	10	12	+18	2	4	0.218552	0.410360
19	4	22	11	+18	16	32	0.219443	0.409340
23	4	34	8	+18	27	46	0.220582	0.408379
27	4	46	2	+18	35	43	0.221967	0.407470
July 1	4	57	52	+18	40	23	0.223590	0.406606
5	5	9	37	+18	41	47	0.225444	0.405785
9	5	21	17	+18	39	58	0.227522	0.404999
13	5	32	50	+18	34	59	0.229814	0.404236
17	5	44	15	+18	26	56	0.232313	0.403489

F. E. SEAGRAVE.

New Asteroids.—The following minor planets have been added to our list since our last note:

	Discovered by	at	Local M. T.	h	m	R. A. h	m	Decl. °	′	Mag.
1903 LQ	Dugan	Heidelberg	Apr. 20	9	44.0	14	04.6	−7	23	12.5
LR	Wolf	"	28	10	43.0	14	38.3	−14	33	12.2

1903 LP has been identified with (406), 1895 CB.

Ephemeris of Brook's Comet for the Return 1903-04.

Berlin Midn. 1903.	α h	m	s	δ °	′	″	log *r*	log Δ
June 20	21	26	39.38	−24	32	8.4	0.3780	0.20134
21		26	57.28	24	33	49.6		
22		27	13.60	24	35	37.0		
23		27	28.34	24	37	30.5		
24		27	41.46	24	39	29.9	0.3749	0.18758
25		27	52.94	24	41	35.1		
26		28	2.80	24	43	46.1		
27		28	11.02	24	46	2.7		
28		28	17.60	24	48	24.9	0.3718	0.17411
29		28	22.52	24	50	52.5		
30		28	25.78	24	53	25.3		
July 1		28	27.38	24	56	3.2		
2		28	27.31	24	58	46.0	0.3687	0.16099
3		28	25.56	25	1	33.5		
4	21	28	22.14	−25	4	25.6		

Ephemeris of Brook's Comet for the Return 1903-04.—Continued.

Berlin Midn. 1903.	α h	m	s	δ °	′	″	log r	log Δ
July 5	21	28	17.05	−25	7	22.0		
6		28	10.28	25	10	22.6	0.3657	0.14833
7		28	1.84	25	13	27.2		
8		27	51.73	25	16	35.5		
9		27	39.94	25	19	47.4		
10		27	26.47	25	23	2.6	0.3627	0.13625
11		27	11.33	25	29	21.0		
12		26	54.52	25	27	42.1		
13		26	36.04	25	33	5.7		
14		26	15.91	25	36	31.4	0.3596	0.12482
15		25	54.18	25	39	59.0		
16		25	30.87	25	43	27.3		
17		25	5.99	25	46	57.0		
18		24	39.55	25	50	27.5	0.3566	0.11418
19		24	11.56	25	53	58.3		
20		23	42.06	25	57	29.0		
21		23	11.12	26	0	59.2		
22		22	38.75	26	4	28.3	0.3536	0.10444
23		22	4.97	26	7	55.9		
24		21	29.86	26	11	21.7		
25		20	53.48	26	14	45.1		
26		20	15.87	26	18	5.7	0.3506	0.09570
27		19	37.07	26	21	23.2		
28		18	57.16	26	24	36.6		
29		18	16.20	26	27	46.0		
30		17	34.27	26	30	50.7	0.3477	0.08811
31		16	51.41	26	33	50.3		
Aug. 1		16	7.69	26	36	44.3		
2		15	23.19	26	39	32.4		
3		14	37.98	26	42	14.2	0.3448	0.08170
4		13	52.12	26	44	49.2		
5		13	5.68	26	47	17.0		
6		12	18.77	26	49	37.3		
7		11	31.44	26	51	49.7	0.3420	0.07655
8		10	43.76	26	53	53.8		
9		9	55.83	26	55	49.3		
10		9	7.72	26	57	35.8		
11		8	19.52	26	59	13.0	0.3392	0.07271
12		7	31.30	27	0	40.5		
13		6	43.14	27	1	58.1		
14		5	55.14	27	3	5.5		
15		5	7.39	27	3	2.3	0.3364	0.07020
16		4	19.95	27	4	48.4		
17		3	32.91	27	5	23.5		
18		2	46.39	27	5	47.4		
19		2	0.46	27	5	59.9	0.3337	0.06904
20		1	15.22	27	6	0.7		
21	21	0	30.75	27	5	49.7		
22	20	59	47.13	27	5	26.8		
23		59	4.47	27	4	51.9	0.3310	0.06919
24		58	22.85	27	4	4.8		
25		57	42.35	27	3	5.5		
26		57	3.02	27	1	54.1		
27		56	24.95	27	0	30.4	0.3284	0.07060
28		55	48.25	25	58	54.5		
29		55	12.95	26	57	6.4		
30		54	39.10	26	55	6.2		
31	21	54	6.78	−26	52	54.0	0.3259	0.07321

GENERAL NOTES.

The editor is in receipt of the first number of the *Bulletin of the Flammarion Astronomical Society* of Montpellier, France, which was issued for April.

This initial number contains 24 pages devoted to the publication of the Constitution of the Society, reports of the November, December, January and February meetings of the Society, a brief history of the old Observatory of Montpellier, and two papers read before recent sessions. The first of these, The Utility of an Atronomical Society, is written by M. Maye, and the second, The Different Systems Proposed for Explaining the Motions of the Heavenly Bodies, by G. Tramblay, both charter members of the Flammarion Astronomical Society of Montpellier.

Errata Occurring in May Number.—Mr. Liugid'Auria's article was reprinted from the March number of *The Journal of the Franklin Institute*, instead of May, as stated on page 254.

The word "meteoric," occurring ten lines from the bottom on page 247 should have read *metonic*.

Wentworth's Revised Trigonometry.—This second revision of the Wentworth Trigonometry contains only so much matter as is taught in the best schools and colleges. The matter is carefully selected, demonstrations clear and concise, which is so common in other books by the same author; figures clear and definite, exercises abundant and the five place tables are easy to read and to use.

This revision is an improvement on that of 1882 in several particulars.

Milne's Advanced Algebra.—The reputation of William J. Milne, as writer on elementary text books in mathematics is so well and favorably known that teachers in these branches have come to expect good things when anything new appears. This algebra presents the essentials of the branch usually given in elementary and higher algebra. The treatment of the subject matter is full and rigorous, and if the book is used by student and teacher as intended by the author, it will give a scholarly basis for specializing in this science.

We are glad to see the use of modern methods employed for the explanation of principles that touch the higher mathematics especially in imaginaries, determinants and the graphical representation of equations and roots.

A Plan for the Endowment of Astronomical Research is the title of a pamphlet recently published by Professor E. C. Pickering, Director of Harvard College Observatory, to several points of which we would call the attention of our readers.

Professor Pickering foresees a near day when those who have amassed the immense fortunes of this generation will be seeking for a channel in which to bestow somewhat of the accumulation. Science has ever attracted such patrons, and especially has astronomy so done, and Professor Pickering believes that owing to the brilliant progress in astronomical lines, it will prove even more attractive in future. Many past gifts have been unfortunate, and unwise, since it is not unknown to find an Observatory and no telescope; or a telescope and no astronomer; or valuable observations unpublished. The reason given is the lack of consultation between astronomer and donor. Only two Observatories in the world now have a larger annual income than Harvard; because of this, and the

permanency of management insured by the age of the University, and the large financial aid it has always received from eastern Massachusetts people, and the fact that it has had three gifts exceeding one, two and three hundred thousand dollars, and because larger gifts may be expected as a result of the present industrial prosperity, Professor Pickering outlines a plan for the advantageous disposal of an annual income of fifty or one hundred thousand dollars for astronomy by Harvard Observatory in the hope that some lover of the science may see the need of such a gift, and be induced to make it.

There should be a Board of Advisors, consisting of several leading astronomers of the country, to meet once a year, and oftener at first, "to consider how the available income could be best expended in order to receive the greatest scientific return." The Board would consist of Directors of Observatories and retired astronomers. They should be empowered to add temporarily astronomers who were invited to participate in some special work, and who could thus take part in their discussions on equal terms. Board expenses would be paid from the income, and excepting clerk hire, these would be almost the only executive expenses. The Board should invite from all astronomers applications for aid, and suggestions as to expenditures. To avoid duplication of work or omissions of desirable work, relations should be maintained with other research fund trustees. The Advisors, having control of the principal instruments of the country and large sums of money, could set to work any particular corps of workers and ought to secure results far beyond those attainable at any existing Observatory. This plan differs from those already in operation. It would be the aim of the Advisors of this Fund to learn what astronomers desired aid, what instruments now unused were available for work, and what material should be published which for lack of funds was unpublisbed. Its special object would be to determine the needs of astronomers, and to find what subjects were being neglected.

Professor Pickering deems it wise to make a beginning in this co-operative work, hoping to show results that will lead to an early fulfillment of his entire plan. He "invites astronomers of this and other countries to send to him applications for aid. A brief statement of the case in form for publication should be made, generally not exceeding two hundred words in length, with an estimate of the cost, and any additional necessary details. If publication is not desired, it should be stated."

Professor Pickering will then use his best efforts to secure the execution of such of the plans as commend themselves to him. He will also bring them to the attention of officers in charge of the following research funds, with which he is officially connected:

"Rumford Fund of the American Academy. Principal, $52,000. Income available to aid American investigators in light and heat.

Elizabeth Thompson Science Fund. Principal, $26,000. Income available for investigators of all countries in all departments of science. Appropriations seldom exceed $300.

Henry Draper Fund of the National Academy. Principal, $6,000. Accumulated income April 15, 1902, $1,515.99. Available for investigations in astronomical physics, by citizens of the United States.

Advancement of Astronomical Science Fund of the Harvard College Observatory. Principal, $70,000, of which $10,000 is now available as stated above. Income may be used for astronomers of any country."

Among the many fruitful fields for expenditure, Professor Pickering suggests as illustrations three: First, that advanced students in astronomy would be

glad of the chance to continue their studies in Observatories where the telescopes lie unused portions of the clear nights. Another is to enable Professor Kapteyn to supervise the making of a catalogue of northern stars similar to the Durchmusterung. This would contain 900,000 stars, and occupy ten quarto volumes of 300 pages each. A third illustration is the equipment of the Georgetown College Observatory station in Rhodesia, South Africa, so that the Catalogues and Charts of Variable stars, completed for northern regions by Father Hagen, could be extended to the south pole.

"In brief, it is proposed to establish an institution in connection with the Harvard Observatory, whose aim should be to advance astronomy as much as possible by making appropriations under the combined advice of the leading astronomers of the country. Much attention would be paid to neglected subjects, especially to those which cannot be provided for by later observations, to secure for persons properly qualified, the use of powerful telescopes now idle and therefore useless, and, in general, to secure for the person best qualified for any given research the best possible means of carrying it on. It would provide means for coöperation, and would aim at the advancement of astronomy, regardless of country or any personal considerations. The cost of this plan, if fully carried out, would be less than that of a first-class Observatory, and it could be fairly tried for a short time, at a moderate expense. For success, it must be wholly unselfish and this condition permanently secured, the investments must be safe, and the net income large. It is believed that no guardian would more surely fulfil these conditions than the Corporation of Harvard College."

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WM. W. PAYNE,
Northfield, Minn., U. S. A.